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JOURNAL OF THE AERONAUTICAL SCIENCES

VOLUME 8 NOVEMBER, 1940 NUMBER 1

An Experimental Determination of the Lift of an Oscillating Airfoil*

ELLIOTT G. REID AND WALTER VINCENTI

Stanford University

ABSTRACT

Wind tunnel tests were conducted to determine the characteristics of the lift of an airfoil performing simple harmonic pitching oscillations about a spanwise axis. The experimentally determined lift ratios and phase angles are compared with the values predicted by the two-dimensional theory of oscillating airfoils.

It is found that for reduced frequencies less than 0.7 the experimental results agree qualitatively, but not quantitatively, with theoretical predictions. However, for the higher reduced frequencies investigated, 0.7 to 0.95, the lift ratio is found to vary in the sense opposite to that predicted by theory. Since airplane wing flutter has been reported at reduced frequencies of 0.69 and higher, this discrepancy would appear to cast some doubt upon the applicability of existing theory to the practical problems of flutter.

INTRODUCTION

EXTENSIVE theoretical studies of the non-uniform motion of airfoils have been made to aid in the understanding and solution of the problems of wing flutter, gust loadings, flapping-wing flight and accelerated flight in general. In particular, the necessity of preventing wing and tail flutter in aircraft has caused the oscillatory motion of airfoils to receive especial attention. The subject of the present report is an experimental investigation of the validity of this phase of the theory. As a preface to the description of the work, a brief résumé of existing knowledge of the subject is presented below.

Among the numerous theoretical studies of the non-uniform motion of airfoils which have been made, those best known in this country are the works of Theodorsen[1] and of von Kármán and Sears.[2] These, as well as others, yield identical results for the particular case considered here—that of an airfoil which performs sinusoidal pitching oscillations under conditions of two-dimentional flow. However, not even this special case has previously been subjected to thorough experimental investigation.

The accepted theory of non-uniform airfoil motion is based upon the following concepts: Oscillatory motion introduces two effects which are absent in uniform motion. One arises from the non-uniform acceleration of the fluid in the direction normal to that of the translatory motion. The other originates in the velocities induced at the position of the airfoil by the wake of transverse vortices discharged as the result of the variation of lift. The flow about an oscillating airfoil thus depends not only upon the attitude and velocity, which are the controlling factors in uniform motion, but upon the instantaneous acceleration and past history of the motion as well.

The simplifying assumptions utilized in developing the theory are:

(1) The motion takes place in the ideal fluid.

(2) The strength of the circulation around the airfoil is such as to preclude flow around the trailing edge at all times.

(3) The airfoil may be replaced by a flat plate.

(4) The amplitude of oscillation is small.

(5) The vortices of the wake remain fixed with respect to the undisturbed fluid.

The first three of these assumptions constitute the foundation of the classical theory of the lift of thin airfoils in steady motion; the second is, of course, the familiar "Kutta-Joukowski condition." The last two assumptions are mathematically convenient but probably not essential; they allow all points of the airfoil and wake to be treated as though they lay in the same plane.

* A summary of the junior author's thesis (Engineer, Stanford 1940). The investigation was conducted under supervision of the senior author.

Presented at the Second Annual Meeting, I.Ae.S., Pasadena, California, June 24–26, 1940.

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The lift characteristics predicted by the theory for the case of sinusoidal pitching oscillation are:

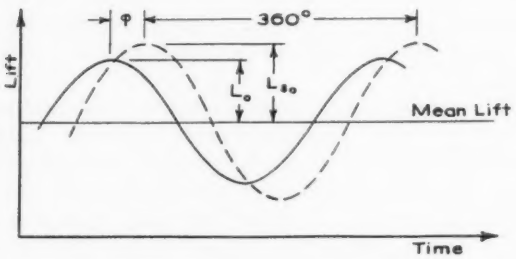
(a) The lift will vary sinusoidally.

(b) The variation of lift may be either greater or less than that which would occur if the oscillation were infinitely slow, *i.e.*, if at each angle of attack the lift were that corresponding to steady motion.

(c) The variation of lift may either lead or lag that of the angle of attack.

(d) The phase angle and amplitude of the variation of lift will depend upon the location of the axis of oscillation* and upon a non-dimensional parameter known as the "reduced frequency."

These predictions are diagrammatically illustrated by Fig. 1. The broken-line sine curve defines the variation of lift which would occur if at each angle of attack the lift were that corresponding to steady motion. This hypothetical curve is designated the "steady state lift."** The solid-line sine curve represents the actual variation of lift which occurs during a particular sinusoidal pitching oscillation. When the axis of



Phase angle = φ $\quad$ Lift ratio = $\frac{L_o}{L_{s_o}}$

$\varphi = f_1(k)$ $\quad$ $\frac{L_o}{L_{s_o}} = f_2(k)$

where

k = reduced frequency = $\pi \frac{nc}{V}$

FIG. 1. Definition of phase angle and lift ratio.

oscillation is fixed, the theory defines the phase angle φ and the lift ratio L_o/L_{s_o} as functions of the "reduced frequency," k.

The physical significance of the reduced frequency becomes apparent when one examines the definitive equation

$$k = 2\pi \frac{nb}{V} = \frac{\pi nc}{V} = \frac{\pi n}{(V/c)}$$

in which n = absolute frequency of oscillation (cycles per sec.)

b = half chord length (ft.)

c = chord length (ft.)

V = velocity of translation (ft. per sec.)

The reduced frequency is seen to be simply π times the number of oscillations performed by the airfoil while it moves forward one chord length.

It is important to note that the theoretical lift ratio and phase angle are independent of the amplitude of oscillation and mean attitude of the airfoil so long as the linear range of the lift *vs.* angle of attack curve for the steady state is not exceeded during oscillation.

At the time the present investigation was begun, no conclusive experimental verification of the theory of oscillating airfoils had been accomplished. The tests made in this country by Reid[3] and in England by Frazer and Duncan,[4] antedate development of the theory and the results are not readily amenable to analysis. Subsequent work by Cicala,[5] in Italy, involved such experimental uncertainly as to be inconclusive. However, the report of Silverstein and Joyner,[6] which was published just after completion of the present experiments, contains evidence of qualitative verification of the predicted phase angle relationship.

Objectives and Scope of Experiments

Although measurements of the lift and moment under numerous conditions of oscillation would be required for complete verification of the theory of non-uniform motion, it was believed that a study of one of these quantities under a single condition would yield valuable indications of the validity of the basic concepts and simplifying assumptions. An investigation of the lift of an airfoil which performs sinusoidal pitching oscillations about a spanwise axis was selected for this purpose.

The experimental program was intended to include the range of reduced frequencies between 0.2 and 1.5. Actually, experimental difficulties prevented the attainment of reduced frequencies greater than unity. However, the influences of both reduced and absolute frequencies were investigated within this range as were the effects of amplitude of oscillation and mean angle.

Apparatus

The experiments were carried out in the wind tunnel of the Guggenheim Aeronautic Laboratory at Stanford University. This tunnel is of the open return, free-jet type and has a circular working section 7.5 feet in diameter.

The model, a 15 by 36 inch N.A.C.A. 0015 airfoil, which consisted of a steel tube spar, five dural ribs and a one-piece sheet aluminum skin, was installed between vertical partitions as shown in Fig. 2. The driving mechanism will be seen outside the right-hand boundary of the airstream. A transverse drive shaft, housed within a streamline fairing, communicated the oscillatory motion to the model through a plate-type universal joint. The left-hand end of the airfoil spar was supported by a special force recording dynamometer which was entirely enclosed within the left-hand partition.

* The theory restricts the position of the axis to points of the chord line or its prolongation.

** Not to be confused with the term "quasi-steady lift" employed by von Kármán and Sears.

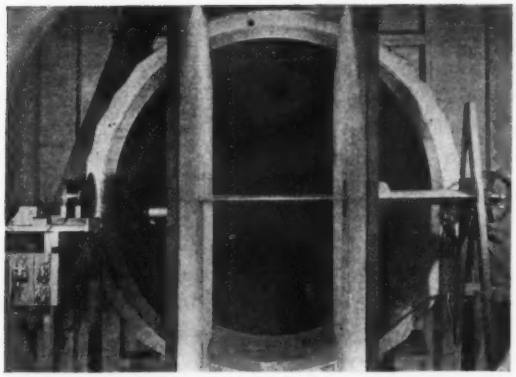


FIG. 2. General view of apparatus (as viewed from downstream).

Details of the driving mechanism may be seen in Fig. 3. The driving link, which was attached to the transverse shaft by a knuckle joint, was made to sweep out a cone by the rotation of the belt-driven flywheel;

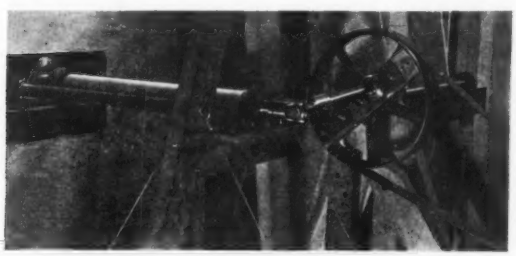


FIG. 3. Driving mechanism (streamlined housing removed).

a rotational oscillation was thus imparted to the drive shaft. The amplitude of the oscillation could be varied by altering the radial location of the driven end of the link, while adjustment of the mean angle of the model was provided for in the universal joint at the inner end of the drive shaft. The geometry of this mechanism was such that the actual angular velocity deviated from that for simple harmonic oscillation by less than 0.25 per cent when the amplitude was $\pm 5°$.

The recording dynamometer is shown in Fig. 4 without the light-tight covers used during operation. This device was built into a 12 by 3 inch steel channel, of about 6 ft. length, which was bolted to the floor and braced by an oblique strut; care was taken to prevent contact between the channel and enclosing partition structure. The dynamometer itself (Fig. 5) consisted of a short, horizontal cantilever spring A which was anchored to the channel and in turn supported the free end of the airfoil spar on a self-aligning ball bearing located in the block B. The application of a lift force to the airfoil produced a minute deflection of the spring, a correspondingly larger deflection of the extension arm

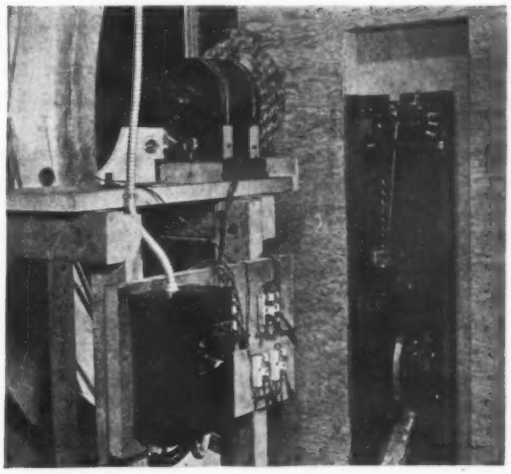


FIG. 4. Recording dynamometer (light-tight cover removed).

C and stylus D and a considerable angular deflection of the pivoted mirror E. This caused the reflected light beam FGIK to sweep along the slit of the motor driven recording camera K. A stylus of adjustable eccentricity was provided at D for variation of the magnification and damping was accomplished by use of the arm L and the vane and dash-pot M. The use of very stiff springs and high magnification ratios (as great as 4000:1) made it possible to limit the inertia forces arising from

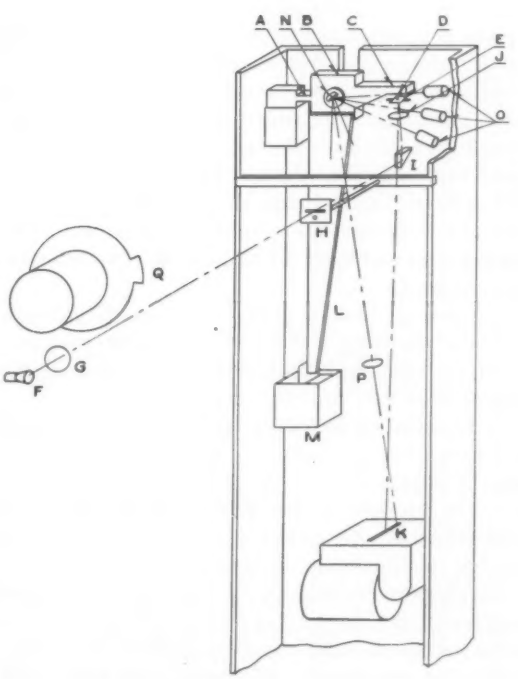


FIG. 5. Diagram of recording dynamometer.

motion of the model to a fraction of one per cent of the applied lift forces.

A time scale was incorporated in the record by interrupting the recording light beam by the synchronous motor driven shutter Q.

The passage of the airfoil through its mean and extreme positions was recorded by the sweeping of three light beams back and forth across the slit of the camera. These beams, originating in the appropriately adjusted "lighthouses" O, were reflected by a small mirror at N which rotated with the airfoil.

The vertical partitions at the tips of the airfoil were plywood covered wooden structures of approximately 3.5 inches thickness. To minimize boundary layer thickness, the inner surfaces were plane throughout their whole extent and the leading edges were thin and sharp. Clearances between the model and partitions were approximately 0.04 inch.

Procedure and Tests

The natural frequencies of the dynamometer with model in place were found to be 78 and 115 cycles per second for the light and heavy springs, respectively. At an oscillation frequency of 8.82 cycles per sec., the highest used in the tests, the lag of the recorded deflection with respect to the impressed force was found by analysis to be inconsequential (0.45°) even when the lighter spring was used.

Velocity surveys of the test section were made at three speeds with the model at zero angle of attack. Variations of velocity distribution with speed were found to be practically imperceptible.

Since the magnification ratio of the dynamometer was changed for each test, a calibration of the recording mechanism was included in each record. This was done at the beginning of the record by recording the position of the light beam for zero load and for a known concentrated load applied at the midspan point of the model. This sufficed to determine the calibration factor for each test because a linear relationship between beam displacement and applied load had been experimentally demonstrated.

The steady state lift curve of the airfoil was established by recording the lift at a dynamic pressure of 6.9 lb. per sq.ft. with the airfoil set at angles of attack ranging from $-2°$ to $+17°$.

Each oscillation test was preceded by the two calibration runs mentioned above. In addition, the steady state lift experienced by the airfoil in its extreme position was recorded at the speed corresponding to the oscillation test. After these preliminaries, a record was made of the lift during oscillation.

The experiments successfully completed included nine oscillation tests made at an absolute frequency of 4.24 cycles per second and one at an absolute frequency of 8.82 cycles per second. All but one were made with a mean angle β of zero degrees; in that one ($n = 4.42$) the mean angle was $-5°$. All but two were made with an amplitude α_0 of $\pm 5°$; in those two ($n = 4.42$) the amplitudes were $\pm 2.5°$ and $\pm 7.5°$. The range of reduced frequency covered by the tests extended from 0.215 to 0.958.

Results

Two typical test records are shown (as mounted for analysis) in Fig. 6. The upper strip of each complete record contains the two calibration measurements necessary to determine the scale of the force records. It also

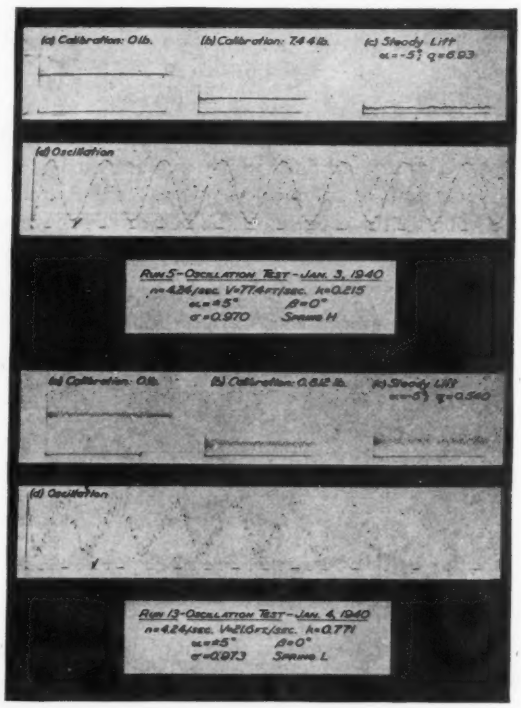

(a) Calibration: 0 lb.
(b) Calibration: 7.4 lb.
(c) Steady Lift
(d) Oscillation
RUN 5 - OSCILLATION TEST - JAN. 3, 1940
(a) Calibration: 0 lb.
(b) Calibration: 0.812 lb.
(c) Steady Lift
(d) Oscillation
RUN 13 - OSCILLATION TEST - JAN. 6, 1940

Fig. 6. Typical test records.

contains the measurement of the steady state lift of the airfoil at the extreme angle of attack attained in the angular oscillation. The base line that appears at the bottom of these records was traced by the beam from one of the lights of the position indicating system. The lower strip contains the record of the oscillating lift. The sinusoidal lift curve appears as a broken line; the breaks, $1/30$ of a second apart, provide the time scale. Indications of the position of the airfoil appear at the bottom of the oscillation records as a series of dots and dashes. The dots indicate the passage of the airfoil through its mean position, while the dashes correspond to the extreme positions. These marks, together with the base lines in the calibration and steady lift records, defined a convenient reference for the measurement of the ordinates of the force curves.

It can be seen that the records of the oscillating lift are marred by the presence of a secondary fluctuation of relatively high frequency. This fluctuation was evidently the result of a self-induced vibration of the airfoil or recording mechanism, but efforts to discover the source of energy input or to damp out the vibration were unsuccessful. As a result it was impossible to obtain the desired data by measurement directly from the records.

Since the secondary fluctuations were of high frequency relative to the fundamental variation in lift, it was possible to separate out the variation in lift with good accuracy by means of a numerical harmonic analysis. Accepted methods of analysis[7] were applied to ordinates of the lift curve taken at 48 equal intervals in a given cycle; and the amplitude of the fundamental harmonic of the curve and its phase shift relative to the mean position dots were determined. The lift ratio was then obtained by proper comparison of the resulting amplitude with the deflection of the light beam in the steady lift record. The phase angle was provided directly by the phase shift computed from the harmonic analysis.

Actually the latter steps in the analysis were complicated by certain small corrections which were necessary to compensate for inadvertent misadjustments of the recording apparatus. These corrections amounted to about 5 per cent in the values of the lift ratios and somewhat less than 4° in the phase angles. The corrections, in general, did not affect the mutual consistency of the data. They did, however, slightly decrease the disagreement between the experimental data and the theoretical predictions. The final results of the tests are shown by the circled points in Fig. 7, where the lift ratio $C_L/C_{L_{so}}$ and the phase angle φ of the oscillating lift are plotted against the reduced frequency k.

For purposes of comparison, theoretically predicted curves are included in Fig. 7. These curves were obtained by application of the general equations of Theodorsen and of von Kármán and Sears to the particular type of oscillation and location of axis (0.40 chord) used in the tests. It can be seen that, throughout the range investigated, the experimental phase angles vary with the reduced frequency in the general manner predicted by theory. The experimental values are, however, consistently smaller than the theoretical ones. For reduced frequencies less than about 0.7, the lift ratios are in qualitative agreement with the theory but are larger than predicted. For reduced frequencies from about 0.7 to 0.95, the experimental lift ratios do not agree with the theoretical results in either magnitude or sense of variation.

Discussion

No satisfactory explanation for the discrepancies between the theoretical and experimental results is known to the authors.

Examination of the possible sources of experimental error indicates that the variation in results between different cycles of the same test is the only one of any consequence. The sets of values at $k = 0.487$ and $k = 0.958$, which are the results of the analysis of three different cycles in each of two test records, indicate that this variation is of the order of 3° in the phase angles and 0.032 or about 4 per cent in the lift ratios. Deviations of this order are insufficient to account for the discrepancies noted between experiment and theory.

If experimental errors are negligible, discrepancies can, of course, arise only from failure of the experimental conditions to conform with those of the theory or from failure of the assumptions of the theory to hold in actuality.

The most apparent difference between the experimental and theoretical conditions is that the airstream did not extend to infinity above and below the airfoil but was bounded by free horizontal surfaces. It is well known that such boundaries have a considerable influence upon the lift of a stationary airfoil. In the present tests, it was found that application of theoretical corrections for this influence[8] resulted in a complete correlation between the relatively low measured slope of the conventional steady state lift curve and the infinite aspect ratio value deduced by other investigators[9] from the results of tests of wings of finite span. What effect the finite stream has upon the lift of an oscillat-

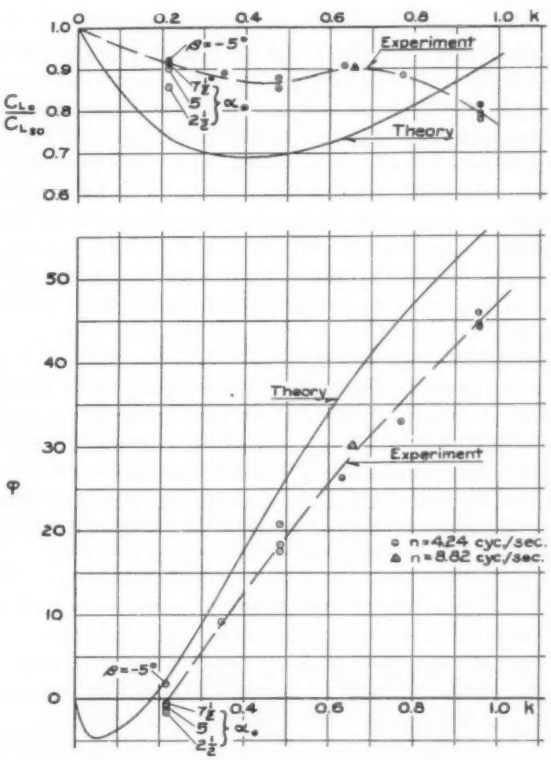


Fig. 7. Lift ratio and phase angle *vs.* reduced frequency.

ing airfoil is not known at present, but it should be remembered as a possible source of the discrepancies between theory and experiment.

A second shortcoming of the experimental installation was the possible deviation from two-dimensional flow caused by leakage between the tips of the airfoil and the vertical partitions. The extent of this deviation is not known, but its effect is undoubtedly small as compared with that of the finite dimensions of the stream, since the latter influence satisfactorily accounts for the slope of the steady state lift curve of the airfoil.

A third shortcoming, the use of an airfoil of moderate thickness instead of a flat plate is thought to be of no consequence.

Among the assumptions of the theory, one which is not fulfilled in actuality is that of the perfect fluid. It is to be expected that the existence of finite viscosity in a real fluid may cause some discrepancy between the theoretical and actual characteristics of an oscillating airfoil somewhat as it does in the stationary case. It is probable, however, that the boundary layer in the oscillating case is itself oscillatory in character and that its action may therefore be considerably different from that of the boundary layer in steady flow. Whatever the effect, the close agreement shown in Fig. 7 between the results of the single test at 8.82 cycles per second and the adjacent points for 4.24 cycles per second suggests that it is substantially independent of the Reynolds Number.

The second assumption of the theory, that there is no flow around the trailing edge of the airfoil at any time, is certainly open to question. It is known, for example, that a change in the attitude or motion of an airfoil is accompanied by flow around the trailing edge for a short time following the change. Since oscillatory motion may be thought of as a continuous series of such changes, it might be supposed that flow around the trailing edge does actually take place during a major part of each oscillation. Whether this flow is of sufficient magnitude to seriously affect the lift of the airfoil is problematical, but it must be borne in mind as a definite physical possibility.

The theoretical treatment of every point of the airfoil and wake as lying in a plane appears to be justified within the range of the present tests by the excellent agreement between the lift ratios and phase angles for three different amplitudes of oscillation α_0 at the same absolute and reduced frequencies (n = 4.24 cycles per second, k = 0.215).

Conclusions and Recommendations

In conclusion, it may be said that the results of this study agree qualitatively, but not quantitatively, with the predictions of the theory of oscillating airfoils for reduced frequencies less than 0.7. For reduced frequencies from 0.7 to 0.95, the phase angles of the oscillating lift continue in qualitative agreement with the theory; the lift ratios, however, vary in the sense opposite to that predicted.

It is interesting to note that this latter disagreement occurs in part of the range of reduced frequencies from 0.69 to 1.14 within which Küssner[10] observed actual cases of airplane wing flutter. This would appear to cast some doubt upon the applicability of existing theory to the practical problems of wing flutter.

The need for further experimental work with oscillating airfoils is apparent. The results of this investigation should be checked and extended well beyond the range of reduced frequency in which flutter is likely to occur. If sizable discrepancies still appear, attempts should be made to discover their origin. It is thought that thorough investigations of the influence of finite stream dimensions and of flow conditions at the trailing edge are most likely to lead to the desired explanation.

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The Application of an Electromagnetic Indicator to Internal Combustion Engine Problems

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J. H. LANCOR, *Sperry Gyroscope Company*
LEIGHTON DAVIS, *United States Military Academy*

Introduction

INDICATORS designed to produce continuous records of cyclic pressure variations have long been recognized as valuable aids to the study of internal combustion engine problems. Many instruments have been constructed and successfully used as continuous pressure indicators, but at the present time no one type has been adopted for general use by the various testing organizations interested in engine work. On the other hand, there are certain points of similarity among all types of high-speed pressure indicators. In each, some means for converting pressure variations into mechanical displacements is coupled to a second system adapted to the production of a permanent record on some material suitable for receiving a mechanical or photographic trace. The means for converting pressure changes into mechanical displacements is usually a spring-restrained piston moving in a cylinder or a diaphragm which may or may not be backed up by an auxiliary spring.

Much greater choice is possible in the means used to record the displacements corresponding to pressure changes acting on the piston or diaphragm and many ingenious methods have been devised for carrying out this function. Mechanical recording arrangements of which the Maihak Indicator[1] is typical are suitable for slow-speed engines and give good results up to some high-speed limit determined by inertia effects in the system. By careful design this upper speed limit has been extended into the region of two thousand revolutions per minute of a four-cycle engine. In some cases the range of satisfactory indicator operation has been extended by increasing the stiffness of the indicator spring and accepting the reduced deflections of the record as in the Micro-Indicator described by Collins.[2] A second method for obtaining the high natural frequency required in the mechanical system with satisfactory record displacements is to use a comparatively stiff spring with magnification of the resultant small deflections by means of an optical system similar to that of the Midgley Optical Indicator.[3] All indicators which record mechanically or photographically from an optical system require that the whole unit be near the point at which the indicator is attached to the engine and for this reason must have indicating systems able to operate satisfactorily under severe conditions of vibration. In addition to the problems introduced by vibration, the indicator itself must be so large that installations are often either difficult or impossible under service conditions.

Electrical indicators use either a spring and piston system or a diaphragm to receive pressure changes, but differ from mechanical or optical indicators in that some means is used to convert the resultant mechanical displacements into electrical changes which in turn actuate a remote recording oscillograph. The unit which receives pressure changes and gives an electrical output usually has approximately the same size as a spark plug and is called the pick-up. The pick-up is rugged and can easily be connected to the engine cylinder while the larger and more delicate recording system can be located at some convenient place away from the engine cylinder. Cathode ray oscillographs now commercially available are of such excellence that it is fair to say that any present-day electrical indicator will use a cathode ray oscillograph for indicating purposes with a camera for photographic recording. Differences between electrical indicators lie in the method used for converting displacements of the indicator piston or diaphragm into electrical voltage changes suitable for operating the cathode ray oscillograph.

Displacements of the piston or diaphragm in the pick-up of an electrical indicator may produce changes in the three electrical parameters (resistance, capacity and inductance), or in magnetic flux linkages with a coil of wire, or in the pressure acting in the proper direction across a piezo-electric crystal. All of these methods have been used in electrical indicators.

Resistance changes in a stack of carbon discs mechanically compressed by diaphragm deflections are used in the indicator developed from the McCollum-Peters[4] Electrical Telemeter by Martin and Caris[5] working in the General Motors Research Laboratory. A later model of the Carbon Disc indicator has been used extensively for studying pressure changes accompanying detonation, and has been described by Grinstead.[6]

Changes in electrostatic capacity were applied in an

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engine indicator reported by Obata and Josida[7] in 1927. Since that time Schnauffer,[8] Brooks-Smith and Colls,[9] and Roess[10] have described indicators using electrostatic means for controlling the output of pick-up units. Two general schemes have been used in these indicators: (1) a polarizing voltage from a battery has been applied to the condenser plates and the changes in voltages accompanying motion between the condenser plates used to operate the indicating system, or (2) a continuous "carrier frequency" of alternating current has been applied to the condenser plates with the indicating system operated by the output from a rectifier connected in the circuit from the pick-up. Indicators using changes in electrostatic capacity are at present available from Southern Instrument Ltd. in England.

Watanabe,[11] Kluge and Linckh,[12] Watson and Keyes,[13] Schrader,[14] and Batcher[15] have described indicators using the piezo-electric effect in quartz crystals. Piezo-electric indicators are available commercially from the RCA Company of the United States, and from the Zeiss Company of Germany.

Both electrostatic capacity and piezo-electric indicators give satisfactory results if properly handled. On the other hand, the internal impedance of the pick-up is necessarily high so that connection between the pick-up and the indicating system must be carefully treated as to insulation and as to capacity effects in the leads. Both piezo-electric and capacity indicators require amplifiers with abnormally high input impedance which is exceedingly difficult to attain at the low frequencies involved. Piezo-electric crystals are fragile and subject to breakage unless the mechanical features of the pick-up are very well designed. Insulation problems are present in both the piezo-electric and electrostatic types of pick-ups.

Electromagnetic generators offer a simple and convenient method for converting mechanical motions into electrical voltage changes. The required mechanical parts are rugged, and reasonably high output voltages can be obtained from small units without the necessity of using mechanical tolerances beyond the reach of ordinary machine shop equipment. Generating coils for electromagnetic pick-ups of practical size have a relatively low impedance (the order of magnitude of one hundred ohms) and are easily insulated for the voltages which are involved. These various features of the electromagnetic generator for use in engine indicators are often considered as not balancing the "undesirable" characteristic that the output voltage is proportional to the rate of change of displacement in the pick-up piston or diaphragm. In practice the electrical integration of the output from an electromagnetic indicator presents no greater difficulty than the ordinary blocking-condenser resistor combination used between stages in a resistance-coupled amplifier. An integrating amplifier suitable for use with electromagnetic pick-ups will be described later in the present paper.

Electromagnetic generators for pressure pick-ups have been built to use two general schemes of construction. The first scheme uses a moving coil of wire connected to a diaphragm and so arranged as to cut lines of flux in a constant magnetic field when the diaphragm moves, while the second scheme uses a flat diaphragm which acts as one end of an air gap and controls the length of this gap in the manner of the diaphragm used in the conventional telephone receiver. The first application of an electromagnetic generator to the engine indicator problem was carried out by Trowbridge[16] in 1921. The instrument of Trowbridge used a moving coil with an annular air gap. This same scheme was later adapted to the study of detonation by one of the present authors.[17,18] The pick-ups used for this detonation work gave considerable trouble from mechanical damage to the small wires required for winding the moving coil and had natural frequencies in the neighborhood of 15,000 cycles per second which were easily excited by mechanical vibrations of the engine structure. Improvements to the electromagnetic generator system were made by Beale and Stansfield[19] and Draper[20] by substituting the telephone receiver type of generator with a flat diaphragm for the moving coil arrangement. This change in construction not only made the pick-up construction simpler but gave an increased sensitivity and permitted an increase in the natural frequency of the unit of three to eight times. The effect of mechanical vibrations of the engine on the records was greatly reduced when these higher natural frequencies were used. Pressure disturbances accompanying detonation are accentuated on a rate of change of pressure record as compared with a direct pressure record so the detonation studies mentioned above were carried out without integration of the output from the electromagnetic pick-ups. A number of pick-ups were constructed and proved to be reliable over long periods of operation. One of these pick-ups has been used in the M.I.T. Internal Combustion Engine Laboratory for precision studies of detonation over a period of two years without trouble of any kind.

Electrical integration for the output from an electromagnetic pick-up sensitive to mechanical vibration was developed by Draper and Bentley[21] in 1934. In 1936 C. E. Mann[22] applied the same general method to the output of an M.I.T. Moving Coil Pick-up. Mann's results were promising, but pick-up itself introduced so many difficulties that it was decided to improve this unit before carrying out further work on the problem of integration. This led to the development of the flat diaphragm type indicator which will be described below. Beale and Stansfield[19] in 1937 described an integrating system operated from a flat diaphragm type electromagnetic generator pick-up and discussed the advantages of such a system. The units developed by these designers differed in several respects from the pick-ups developed at M.I.T. The reader is referred

to the original articles for a discussion of these differences.

The instrument described in the present paper was built to fill the need for a continuous pressure indicator to be used in teaching the fundamentals of internal combustion engines to cadets at the United States Military Academy. An inquiry directed to the Sperry Gyroscope Company by Lieutenant Davis resulted in a project to use the electromagnetic pick-up unit design already developed in the Internal Combustion Engine Laboratory at M.I.T. as part of an instrument for indicating instantaneous pressures on the screen of a cathode ray oscillograph. The pick-ups were actually constructed in the Ordnance Laboratory at U.S.M.A. The integrating amplifier and auxiliary equipment were built in the Department of Natural and Experimental Philosophy at U.S.M.A. with the help of staff members from that department. The cooperation of C. C. Carter, J. P. Dean and W. A. Downing of the U.S.M.A. faculty was especially helpful. Thanks are also due to P. R. Bassett, F. R. House and H. H. Willis of the Sperry Gyroscope Company for assisting the project in various ways. E. S. Taylor and A. R. Rogowski furthered the work by loaning an M.I.T. Balanced Diaphragm Indicator for test purposes.

General Considerations

Fig. 1 shows schematically the essential parts of the electromagnetic indicator built at U.S.M.A. The cathode ray oscillograph was a commercial RCA instrument with a five-inch tube. The performance characteristics of the standard amplifiers supplied with

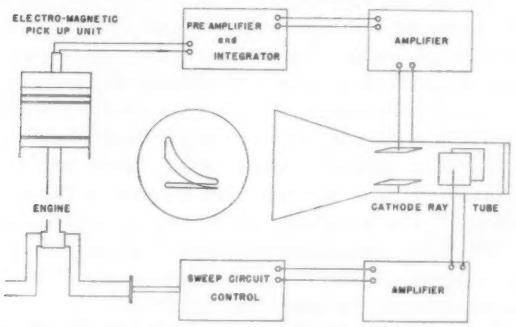

Fig. 1. Schematic diagram of U.S.M.A. electromagnetic indicator.

the cathode ray oscillograph were satisfactory for use with the engine indicator. A complete description of the circuits and the performance of this instrument can be obtained from the manufacturer so no special discussion of this part of the apparatus will be included here.

The pick-up design used at U.S.M.A. was essentially the same as that of the units built at M.I.T. so that the electrical output available for operating the indicating equipment was fixed for the engine pressure variations existing in the test engines at U.S.M.A. With the pick-up performance and the oscillograph characteristics determined, the problem was to design and construct an integrating amplifier suitable for coupling these two units into a complete indicator useful for demonstrations in the U.S.M.A. Engine Laboratory. The engines to be used were a Hill Diesel, operating at speeds between 400 and 700 r.p.m. and a four-cylinder Winton gasoline engine connected to an electrical generator and running at about 1350 r.p.m. No attempt was to be made to study detonation phenomena so that no special effort was used to extend the amplifier response to high frequencies. The auxiliary equipment for controlling the phase of the oscillograph pattern with respect to engine cycle events was designed to fit the engines available for test work.

Electromagnetic Pick-Up

Fig. 2 is a diagram showing the essential parts of the M.I.T. Electromagnetic Pick-Up. A permanent magnet, A, of heat-treated cobalt steel acting through the cold rolled steel core, B, maintains magnetic flux across the air gap, C, between the end of the core and the cold rolled steel diaphragm, D. The equilibrium length of the air gap is about 0.005 inch. The unsupported diameter of this diaphragm is one-half inch and the thickness may have any value greater than about 0.0300 inch for satisfactory operation in high performance engines. The diaphragm has a circular rim about 0.100 inch in axial length which is pressed into

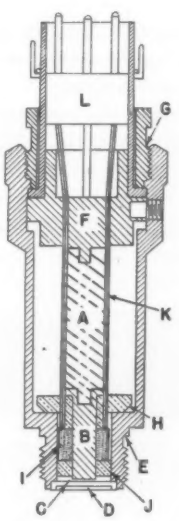

Fig. 2. Diagram showing essential parts of electromagnetic pick-up

the cold rolled shell, E. This shell, is threaded to fit a standard 18-millimeter spark plug hole and supports the entire pick-up system in addition to serving as a return path for the magnetic flux. A properly formed disc of cold rolled steel, F, completes the magnetic

circuit and makes it possible for the ring nut, G, to clamp the magnet in place. This clamping action takes place against the phosphor bronze disc, H, which rigidly fixes the upper end of the core, B, with respect to the shell. The coil, I, which receives the generated voltage is wound on the core and is retained at the lower end by means of the duraluminum disc, J. This disc is held in place by a brass cross pin. Insulated leads, K, are brought out from the terminal system, L, which is similar to commercial connectors designed to perform a like function.

When a diaphragm thickness of 0.030 inch is used, the theoretical deflection of the center of the diaphragm is about 0.8×10^{-6} inch per pound per square inch pressure. This deflection under a given pressure varies inversely as the cube of the diaphragm thickness. The natural frequency of the diaphragm with a thickness of 0.030 inch vibrating in its lowest mode is theoretically about 50,000 cycles per second and increases directly with the first power of the diaphragm thickness. It has been proved by experiment that the actual values of deflection and natural frequency are reasonably near the theoretical values. Cooling, elastic strength and flux-carrying power of cold rolled steel diaphragms with one-half inch free diameter have been found by experiment to be satisfactory under the most severe engine conditions if the thickness is over 0.030 inch. With maximum engine pressure in the vicinity of 500 pounds per square inch an equilibrium gap length of 0.005 inch gives a sensitivity which is satisfactorily constant over the entire range of operation.

Fig. 3 is a photograph showing the external appearance of a pick-up unit on the left with a shell and magnet assembly on the right.

Experimental tests of the performance of the electromagnetic pick-up have been carried out at M.I.T. In these tests oscillograph records were taken from engines in actual operation through a specially constructed non-integrating amplifier of known characteristics. These records were enlarged and integrated

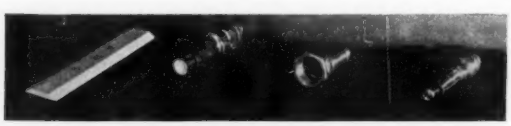

FIG. 3. Photograph of pick-up showing external appearance of assembly and of parts.

by hand to give pressure-time curves. These integrated records were then compared with simultaneous pressure-time cards made with the M.I.T. Balanced Diaphragm Indicator.[23] A number of such comparisons showed that the accuracy of the electromagnetic pick-up was as good or better than the accuracy of the process of integration. It was found that much more precise results could be obtained for comparison purposes by integration of the rate of change of pressure record than by differentiation of the pressure-time record. On the basis of these experiments it was decided that the performance of the electromagnetic pick-up was sufficiently good to justify testing the unit in a complete indicator system.

INTEGRATING AMPLIFIER

The function of the amplifier which must be used to couple an electromagnetic pick-up into a cathode ray oscillograph is to produce the time integral of input voltage variations in such a fashion that all the various component frequencies of a complicated wave are subjected to the same "time delay" in the integrating and amplifying process. If this latter condition is not fulfilled, the shape of the oscillograph record will be different from the true shape of the pressure-time variation which actuated the pick-up unit. In any case the experimental result will not be perfect, but it is possible to keep the resultant errors within reasonable limits.

The integrating circuit consists of a resistance in series with a condenser; the input is connected across the complete circuit and the integrated output is taken from the condenser.[21] If the voltage drop across the condenser is negligibly small compared to the voltage drop across the resistance, the integrating circuit will give perfect performance. The performance will deteriorate as the condenser drop becomes relatively larger. It is immediately obvious that under d.c. conditions all the voltage drop will be across the condenser and the system will not operate, while for rapid changes in the input voltage the voltage drop across the condenser will approach zero and the circuit will integrate perfectly. In practice, the low-frequency limit of operation is usually established when the drop across the condenser is about one per cent of the drop across the resistance. Under this condition the circuit will give an output voltage which varies less than one per cent from the true time integral of the input changes. The integrating circuit used in the indicator described here was fitted with a variable resistance so the accuracy of the integration process could be adjusted with the equipment in operation.

The amplifier to be used with the integrating circuit for an electromagnetic indicator not only has to produce the necessary voltage gain for operation of the cathode ray oscillograph from the pick-up output, but this voltage gain must be independent of the input frequency over the range of frequency components to be handled, and all frequencies within the operating range must pass through the amplifier with the same time delay. In the present case the amplifier was designed to give satisfactory results for demonstrations with the relatively low-speed engines in the U.S.M.A. Engine Laboratory rather than to give refined results from high-performance equipment. The engine speed range

of interest was 400 to 1400 r.p.m. and it was estimated that maximum errors of about ten per cent could be tolerated. On the basis of ten per cent errors in changes taking place within five degrees of crankshaft rotation or at the lowest frequency involved in the pressure cycle the amplifier response was required to vary a maximum of ten per cent from perfection over a frequency range of about 5 to 1000 cycles per second. The performance of the amplifiers in the RCA cathode ray oscillograph falls well within the limits specified so errors from that source were left out of consideration. The designed voltage gain in the amplifier which was constructed was 16,000. At the low-frequency limit of operation the integrating circuit reduced this gain by a factor of about one hundred.

Fig. 4 is a circuit diagram of the integrating amplifier. Two RCA 6J7 tubes are used in conventional pentode voltage amplifier stages. The integrating circuit is placed between the two stages with a rheostat introduced for use as the "integration control." Potentiometers are used in the grid circuit of each tube in order to permit the most advantageous balance of gain between the two stages. A switch is provided for shifting the amplifier from "direct" to "integrating" operation at will. The output of the integrating amplifier was connected directly to the input terminals for the vertical deflection plates in the RCA oscillograph.

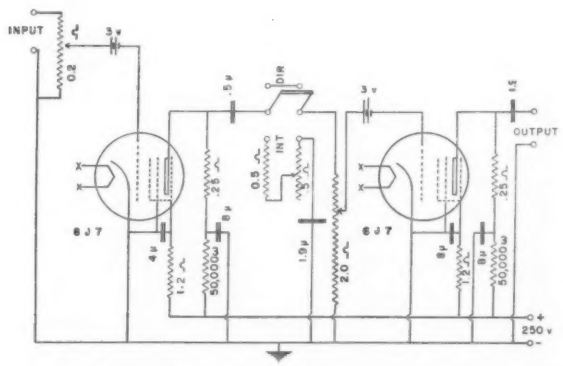

FIG. 4. Circuit diagram of unit for direct or integrating amplification of electrical output from pick-up.

EQUIPMENT FOR PHASING OSCILLOGRAPH TRACE WITH RESPECT TO ENGINE CYCLE EVENTS FOR PRESSURE-TIME OR PRESSURE-VOLUME RECORDS

Pressure-time or pressure-volume indicator cards require that the beam of electrons in the cathode ray tube be swept horizontally in a controlled manner as the output from the integrating amplifier changes the vertical position of the beam in accordance with pressure changes in the engine. Pressure-time cards are produced if the voltage applied to the deflecting plates controlling horizontal position increases linearly with time after some fixed instant in the engine cycle at which the voltage starts from zero. Pressure-volume cards are produced if the voltage applied to the horizontal deflecting plates varies as the position of the piston within the engine cylinder after starting from zero at some definite reference point (usually top center or bottom center) in the crankshaft travel.

In practice, the voltage variation required for pressure-time cards can be obtained by connecting a fixed condenser across the deflecting plates and allowing this condenser to charge through a fixed resistor from a source of constant voltage. Phasing with crankshaft rotation can be obtained by allowing a contactor rotating with the crankshaft to short circuit the condenser terminals for a short time once each revolution of the crankshaft. Pressure-volume cards can be obtained by connecting the output from a special generator driven by the crankshaft to the horizontal deflecting plates. If the voltage output of this generator varies in the same manner as the piston position within the cylinder and the mechanical connection from the crankshaft to the generator is properly phased, the cathode ray beam will move horizontally in the proper fashion to give a pressure-volume trace on the cathode ray screen.

Fig. 5 is a diagram of the electrical circuits used for sweeping the cathode ray spot horizontally and for phasing the records with respect to engine operation. The arrangement for pressure-time records is simply a rotating contactor suitable for instantaneously closing a circuit at any one of four points for each crankshaft revolution and provided with means for adjusting the crankshaft angle at which these contacts take place. The switches, A, B, C, provide for the short circuiting of the capacitator once, twice, or four times per engine revolution, thereby sweeping the electron beam across the face of the C.R. tube every 360, 180 or 90 degrees of crankshaft revolution.

Horizontal deflections for approximate pressure-volume cards are provided by the voltage of a two-pole alternating current generator. Provision is made for adjusting the phase of the output voltage with respect to crankshaft angle by rotation of the field assembly. The wave form of the voltage from the

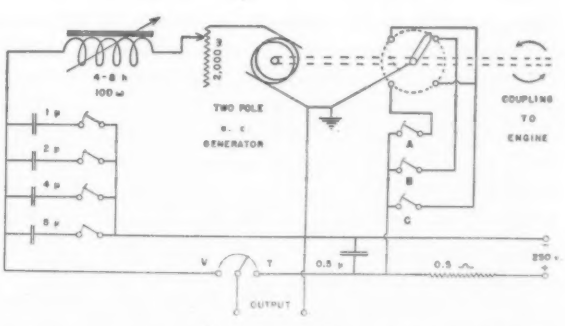

FIG. 5. Diagram of electrical equipment for phasing oscillograph trace with respect to engine cycle events for pressure-time or pressure-volume records.

generator is substantially sinusoidal, but is further modified by an adjustable series resonant circuit, the voltage across the capacitance being used for the deflection. In practice, capacitance and inductance are adjusted to resonance for the frequency delivered by the generator at the test r.p.m. The resistance in the circuit is then increased to as high a value as will still obtain sufficient beam deflection. The end obtained by this procedure is that changes in engine r.p.m. accompanying changes in load cause no phase shift between the voltages representing pressure and the voltages representing piston displacement.

The voltage output from the sweep generator is substantially sinusoidal although some higher harmonics are introduced by the iron core used in the inductance unit. A certain harmonic content in the generator voltage is desirable to compensate for the effect of finite connecting rod length on piston displacements. No effort was made to evaluate the harmonics actually present in the sweep voltage. Instead of this procedure, an actual pressure-time card from this engine was plotted to pressure-volume coordinates, the volume representation being accurate in one case and a sine function in the other. The error introduced by use of a sine wave (without harmonics) was about four per cent. Inasmuch as the equipment was designed for demonstrations of a qualitative nature in connection with instruction in elementary thermodynamics, this error was not considered sufficient to justify the complication of circuits capable of introducing and controlling additional harmonics.

A two-way switch is provided to select the horizontal deflection motion for pressure-time or pressure-volume cards as desired.

Fig. 6 is a photograph showing the external appearance of the electrical units of the U.S.M.A. Indicator. The cathode ray oscillograph and the integrating amplifier are placed on top of the box housing the synchronizing and phasing equipment.

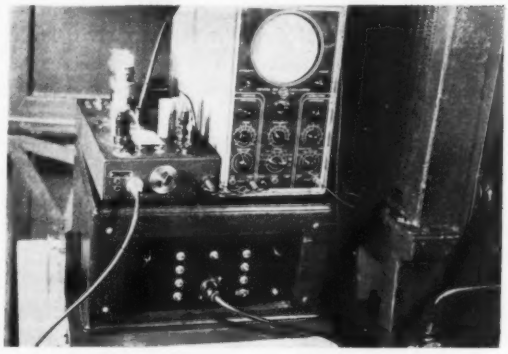

FIG. 6. Photograph showing external appearance of electrical parts of U.S.M.A. electromagnetic indicator.

TESTS OF THE INTEGRATING AMPLIFIER

Electrical tests of the integrating amplifier were carried out by applying a known alternating current voltage to the input terminals at a series of different frequencies and measuring the voltage obtained at the output terminals. The pick-up unit and actual leads between the pick-up and the amplifier were in the circuit during all the tests. Fig. 7 shows the performance characteristic of the amplifier when the integrating circuit is not in use. Fig. 8 shows the performance characteristic of the integrating amplifier with various settings of the "integration control" rheostat.

Phase shift effects in the amplifier were studied by applying the amplifier input voltage to the vertical deflecting plates of the cathode ray oscillograph while the output voltage of the amplifier was connected to the horizontal deflecting plates. This arrangement resulted in an elliptical trace on the cathode ray screen in which the major and minor axes indicate the phase shift taking place through the amplifier. This check showed that the input and output voltages were displaced by very small angles without integration and were displaced almost ninety degrees with integration. This is the normal behavior of the system and proved that the action was substantially correct although the precision of measurement was not sufficient for the results to be used for a quantitative measure of accuracy.

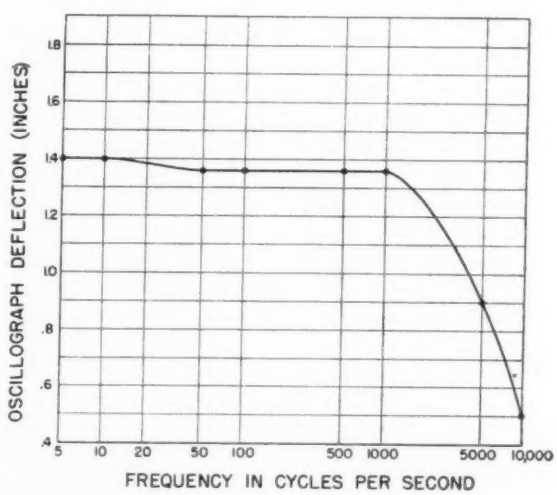

FIG. 7. Direct frequency response characteristic of U.S.M.A. indicator.

The most valuable method for studying the performance of the integrating amplifier was to apply a "square wave" lasting a few thousandths of a second at intervals which could be varied at will. Perfect integration would give a triangular response curve with a steep straight line slope during the square wave action and straight lines of less slope in the opposite direction between the square waves. The action during the

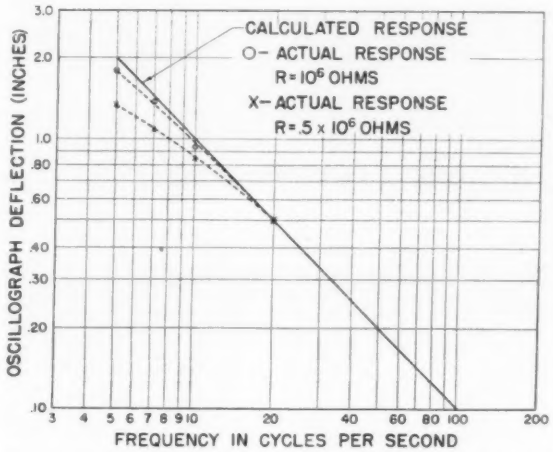

FIG. 8. Integrating frequency response characteristic of U.S.M.A. indicator.

square wave permitted a good estimate of the low-frequency behavior of the system. By spacing the square waves to approximately the time required for one engine cycle, the response of the amplifier to engine operating frequencies could be fairly well determined. Any deviation of the sides of the response triangles from straight lines indicated distortion in the amplifier.

ENGINE TESTS OF THE U.S.M.A. INDICATOR

Fig. 9 shows photographic records made of the oscillograph trace with the indicator connected to a Hill Diesel Engine running at 550 r.p.m. with no load. The upper traces are the rate of change of pressure cards taken with late injection timing and correct injection timing, respectively, while the lower traces show the corresponding pressure records produced by electrical integration of the indicator output.

The overall results from the indicator depended upon so many factors which were difficult to evaluate separately that it was decided to study the indicator performance by taking simultaneous records of engine pressure variations with the U.S.M.A. Indicator and an M.I.T. Balanced Diaphragm Indicator.[23] The accuracy of the balanced diaphragm indicator has been proved by many tests over a period of several years so that results from this instrument can be used for purposes of standardization. Fig. 10 is a diagram showing how the pick-ups from the two indicators were installed in a special fitting which was screwed into a priming cock hole in the head of the Winton gasoline engine. Fig. 11 is a photograph showing the appearance of the pick-up installation. Fig. 12 is a general view of the test installation with the various pieces of equipment designated by letters.

Sample pressure-time records taken from the Winton engine for the four operating conditions specified in Table 1 are given in Fig. 13. Fig. 14 shows a series of pressure-volume cards taken on the Winton engine

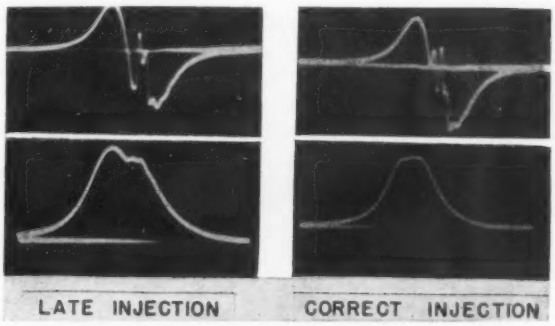

FIG. 9. Sample rate of change of pressure records and corresponding pressure records taken on Hill Diesel engine at 550 r.p.m.; no load.

for conditions corresponding to the pressure-time cards of Fig. 13.

DISCUSSION OF RESULTS

Test results based upon direct comparisons between pressure-time records from the U.S.M.A. Indicator

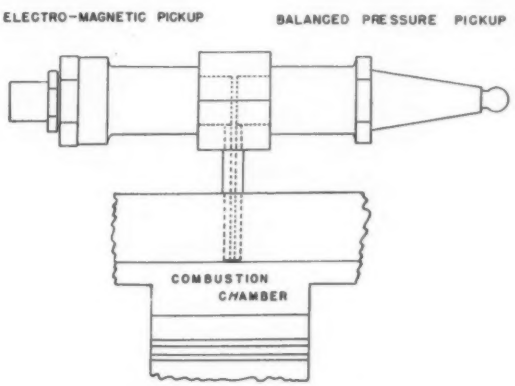

FIG. 10. Diagram showing test installation of electromagnetic pick-up and M.I.T. balanced pressure pick-up on Winton gasoline engine.

and the balanced diaphragm indicator did not permit more than a rough evaluation of the performance of the electromagnetic indicator. This difficulty was

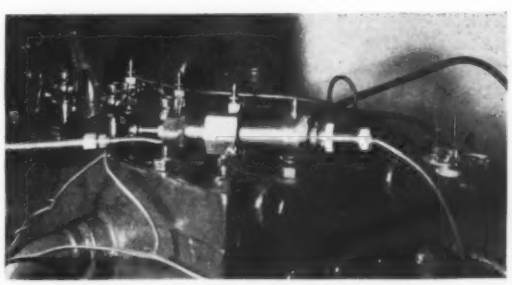

FIG. 11. Photograph showing installation of pick-ups on Winton gasoline engine. Electromagnetic pick-up on right.

due to the lack of uniformity between successive cycles of the Winton engine which resulted in a relatively wide area of points on the spark records from the balanced diaphragm indicator, especially in the high-pressure part of the cycle with combustion in progress. This lack of uniformity between cycles was apparent in the cathode ray screen traces from the electromagnetic indicator and is also shown in several of the cards given in Figs. 13 and 14. It is an inherent characteristic of the balanced pressure indicator that the cards obtained are based on the average of a considerable number of cycles rather than a single cycle. For this reason, average values and the corresponding limits of variation are the only data supplied by such an indicator. On the other hand, the electromagnetic indicator gives a complete record from a single cycle but does not supply any information on which point of the balanced diaphragm pressure record should be correlated with the record from a given cycle. On the actual records the spread of points was so great that uncertainties of ±10 per cent were unavoidable in the high-pressure region of the cards. A second difficulty was an uncertainty of a few degrees in phasing of the pressure-

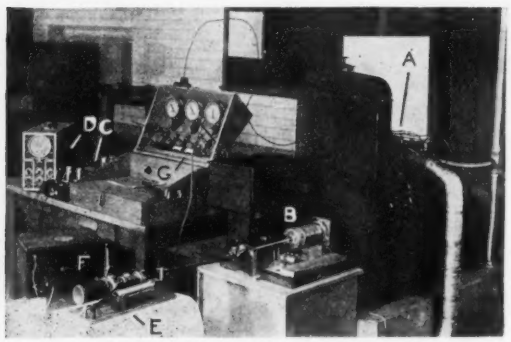

FIG. 12 General view showing test installation of indicators on Winton gasoline engine. A—pick-ups; B—sweep circuit control; C—preamplifier and integrator; D—cathode ray oscillograph; E—recording system for M.I.T. balanced pressure indicator; F—control box for M.I.T. indicator; G—pressure gages and valves for M.I.T. indicator.

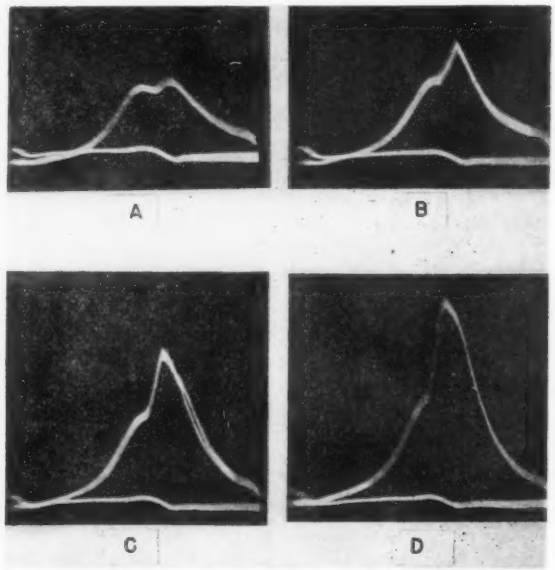

FIG. 13. Sample pressure-time records taken with U.S.M.A. electromagnetic indicator under operating conditions specified in Table 1.

TABLE 1

Comparison between M.I.T. Spark Indicator and U.S.M.A. Oscillographic Indicator

May 31, 1940

Engine: Winton Gasoline Engine, coupled to d.c. Generator
Bore: 2.94 in. Stroke: 4 in. Con. Rod. 10 in. 4 cyl.
Compression Ratio: 4.8:1

Test Conditions:
Fuel: Q.M. contract
("Regular" grade automotive)

Record	Load, Kw.	R.p.m.	(Positive Loop) Plotted PV Area Bal. Diaph. Ind.	Area Photo. Oscillo-graph	Corr. Area	$\frac{As}{Ae}$
A	0	1350	9.56	0.86	9.26	1.03
B	1.79	1340	12.91	1.26	13.5	0.953
C	2.80	1320	16.7	1.56	16.7	1.00
D	3.86	1310	20.5	1.91	20.5	1.00

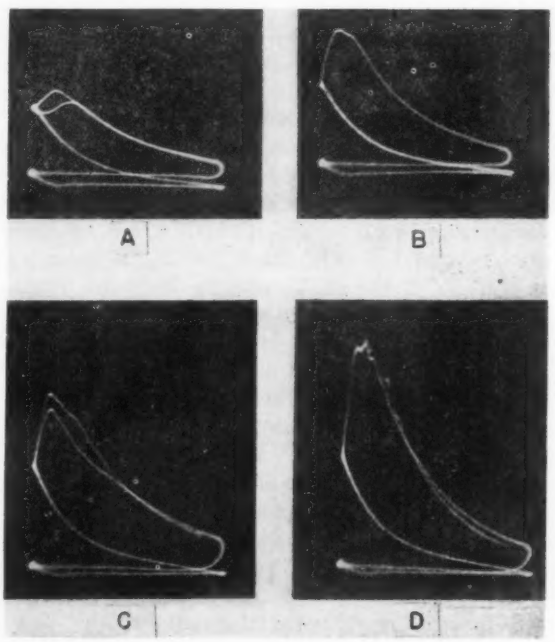

FIG. 14. Sample pressure-volume records taken with U.S.M.A. electromagnetic indicator under operating conditions specified in Table 1.

time cards. This made it impossible to determine accurately corresponding points on cards from the two instruments.

For the reasons mentioned in the last paragraph the best check which could be obtained between the indicator under test and the standard was to observe that the general shape of the electromagnetic indicator cards was similar to the general shape of the pressure-time cards taken with the balanced pressure indicator, and that the variations between successive cycles on the cathode ray tube seemed to fall within the limits of the pressure vibrations recorded by the balanced diaphragm indicator.

As a check on the pressure-volume cards produced by the electromagnetic indicator, average pressure-time cards from the balanced pressure indicator were reduced to a pressure-volume basis and compared with cards photographed from the oscillograph. In general, average cards from the electromagnetic indicator were similar in shape to estimated average cards from the balanced pressure indicator. To compare the indicated work areas from the cards taken by the two indicators, the positive loop (high-pressure loop) areas from several pairs of experimental cards were taken with a planimeter and compared as to constancy of the ratio between areas indicated by the two instruments. Table 1 and Fig. 15 show that the ratio of the areas measured from the two sets of cards was fairly constant over a range of loads on the Winton engine. In the high-load range where the card areas were relatively large and the variations between cycles were relatively small the two indicators gave results which were more consistent than in the low-load range. The check described above is at best an approximation, but it shows that the electromagnetic indicator would be useful for estimating the indicated output of internal combustion engines.

An additional check on the electromagnetic indicator was made by taking pressure-time cards from the Hill Diesel Engine simultaneously with the operation of a high-speed Maihak indicator. Sample cards from this procedure are shown in Fig. 16. The similarity in shape between the two curves is apparent.

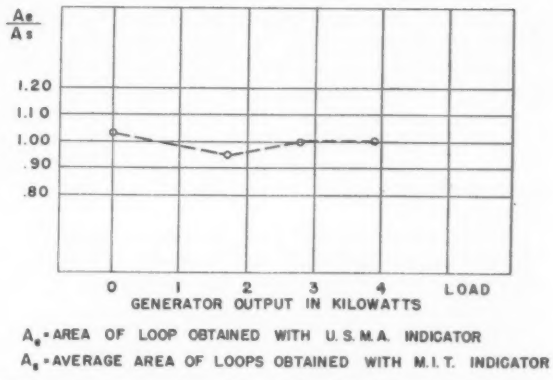

FIG. 15. Comparison of areas of positive loops from pressure-volume records taken with U.S.M.A. indicator with average areas of positive loops from records taken with M.I.T. indicator.

CONCLUSIONS

The tests described above prove that an engine indicator using the electromagnetic generator principle can be built to give worthwhile results in engine research, development testing or teaching demonstrations. The effectiveness of an indicator which can be left in continuous operation for indefinite periods of time without attention of a skilled operator can only be appreciated by personal observations. The U.S.M.A. Indicator, in its present state of development, will serve as a satisfactory instrument for qualitative examinations of operating conditions in engines of any kind and it is certain that the overall accuracy of the equipment can be improved by engineering modifications of the various component parts.

The equipment described in the present paper was used for a period of approximately two months at the United States Military Academy after the complete system was placed in operation. During this time the instrument was used for routine class instruction without interruptions from failure of the equipment. This result, coupled with the fact that an electromagnetic pick-up similar to that used with the U.S.M.A. Indicator has operated satisfactorily without attention for two years in the M.I.T. Internal Combustion Engine Laboratory, demonstrates that the electromagnetic engine indicator is a practical instrument.

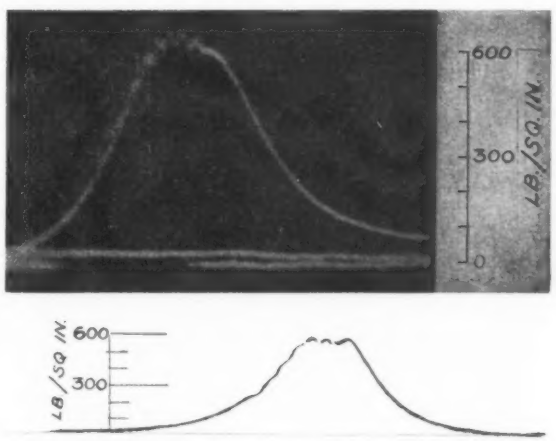

FIG. 16. Comparison of pressure-time record from U.S.M.A. indicator with pressure-time record from Maihak indicator.

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Tests of Pressurized Cabin Structures

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Lockheed Aircraft Corporation

WEIGHT has always concerned the structural engineer. However, as airplane design progressed other factors and demands became of increasing importance. The fuselage of a commercial airplane has to satisfy not only the aerodynamicist and the equipment group, but must also comply with the desires and needs of the passengers. The present idea of an ideal fuselage is one which has low drag, weighs practically nothing, is as large as possible on the inside, and can be pressurized. This paper deals with some of the problems created by the latter three requirements.

Test Set-Up

The introduction of pressure into a fuselage test section creates serious problems at the ends. Bulkheads rigid enough to resist both pressure loads and external loads must be designed. The fixed end of the test section was fastened to a large reinforced concrete block which has a steel face plate $^3/_4$ inch thick and $^3/_4$ inch anchor points at 9 inch spacing (see Fig. 1). These anchor points are designed to withstand a tension force of 15,000 pounds each. The concrete behind the steel face plate is over 24 inches thick. A vertical shear of 250,000 pounds and a bending moment of 50,000,000 inch-pounds can be withstood. The inside of the concrete block is designed for a double door pressure lock or a decompression chamber.

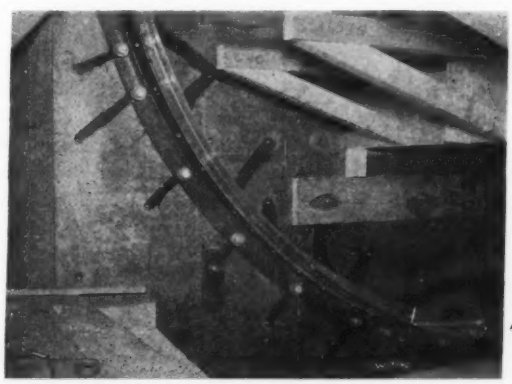

FIG. 1. Close-up photo of test stand.

At the free end of the test section a large steel structure was built which could withstand large pressure, bending, torsion, and shear loads. Fig. 2 shows the loading end bulkhead before being fastened to the structure. Due to the required strength and rigidity this structure weighs 4800 pounds. Fig. 3 is a general view of the fuselage test set-up and shows the test stand, the specimen, and the loading head.

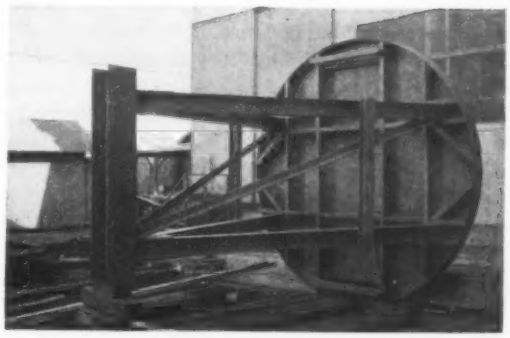

FIG. 2. Rear view of loading head.

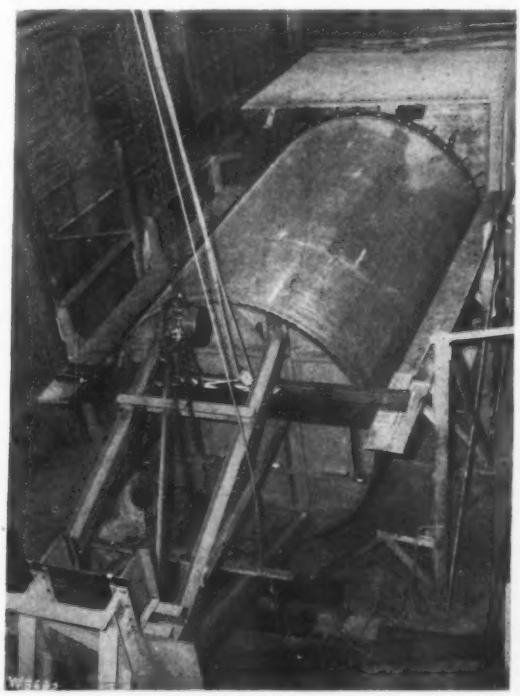

FIG. 3. General view of test set-up.

Presented at the Second Annual Summer Meeting, I.Ae.S., Pasadena, California, June 24–26, 1940.

Bending tests were made on the fuselage test section with and without pressure and a complete set of tests were first made with no cutouts. The object in making a complete set of tests without cutouts was to study the effect of cutouts and to facilitate correlation with theory. The pressurizing was accomplished by attaching an air line from the regular factory supply. The leakage rate was never severe enough to tax a $^3/_4$ inch line. The air pressure in the test section was measured with a 36-inch mercury manometer, and the leakage rate was obtained by the use of a Bureau of Standards air nozzle. Fig. 4 shows the bottom of the specimen under no load; some small buckles and

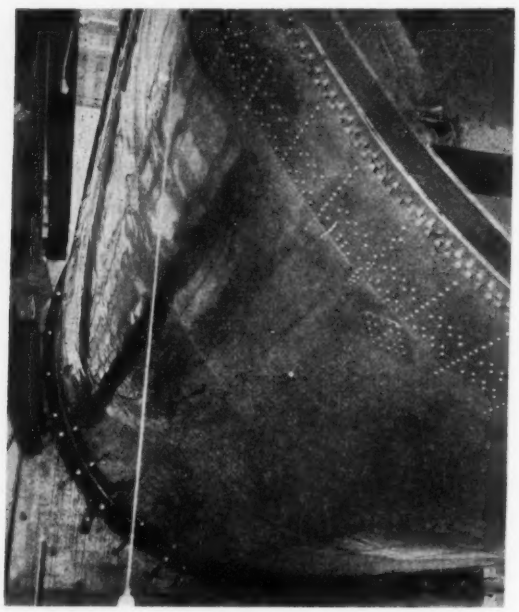

FIG. 4. Bottom view of test section—no load.

wrinkles are visible since the section had been tested a great deal before this picture was taken. Fig. 5 shows the same view as Fig. 4 except that the structure is under high bending and shear load. It is interesting to note how far up on the side sheet the buckles extend.

STRESS MEASUREMENTS

Since one of the main objects of these tests was to obtain results upon which a theoretical analysis could be based for use in further design, it was highly desirable to secure reliable and extensive stress measurements. The additional difficulty of making the measurements in a pressurized chamber had to be considered.

After extensive tests it was decided to use electrical strain gages of the Baldwin-Southwark type.[1, 2, 3] Careful tests have shown that this instrument performs satisfactorily from 55,000 lbs. per sq.in. in compression to 55,000 lbs. per sq.in. in tension when mounted on

FIG. 5. Same view as Fig. 4—with load.

24ST aluminum alloy. With these instruments it has been possible to study stresses in locations where it would be impossible to mount instruments of say the Huggenberger type. The feature of remote reading has proved to be of invaluable help. In the case of the pressurized cabin all leads could be brought out through pressure tight seals, thus enabling the measurements to be made at one place outside of the pressure chamber. As many as forty-four instruments have been in use at one time and a single observer can quite easily read one instrument every twenty seconds.

The instruments can be mounted quite rapidly once the technique has been developed. Fig. 6 shows the method of cementing the instrument to the side of a stiffener. Notice that the instrument can be placed near the neutral axis of the stiffener so that bending stresses do not cause such a serious problem. The time saving in actually attaching instruments can largely offset the time involved in doing the wiring, as compared with, say, a Huggenberger set-up. Successful re-

FIG. 6. Method of attaching strain gage.

sults have been obtained with a circuit which uses only a single wire to each gage.

Bending moments can be obtained by using two instruments as shown in Fig. 7. The two instruments can be seen at the top of the figure. The moment on the member can be calculated if the difference in stress

FIG. 7. Set-up for measuring bending moment.

at the two points, the distance between the two points, and the moment of inertia of the section are known. The set-up for reading twenty-four instruments is seen in Fig. 8. The large box is a potentiometer, although a galvanometer can be used. The black box is a bridge circuit and accommodates twenty-four instruments. In general accuracy and reproducibility, the results of these instruments have been highly satisfactory.

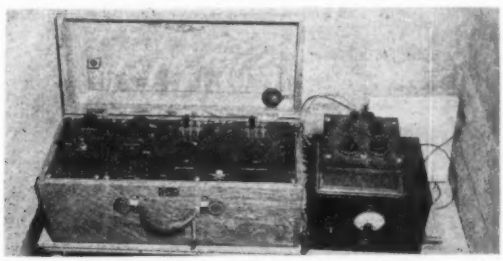

FIG. 8. Equipment used in strain measurements.

EFFECT OF PRESSURE

The main structural problems created by pressurizing are (1) the effect of cutouts, (2) the increased loads on seams and joints, and (3) the loads in non-circular sections. It appears *a priori* that the structure would be stabilized by pressure, but this point must be proved.

Since most of the structural problems of pressure cabins are easily reducible to well known principles of elasticity, an attempt will be made to discuss some of the problems not so easily handled. The problem of quilting will be considered first. The term quilting refers to the bulging of the skin panels between the frames and the stiffeners. A large amount of work has been done, both experimentally and theoretically, on the deflection of thin plates under normal pressure. Nearly all of this, however, has been done on flat plates, while in a pressurized cabin the panels are curved.

If the fuselage were a pure shell with no reinforcement there would be no bulges or quilting; however, in the modern fuselage there must exist frames and stiffeners upon which no pressure forces act directly. Since the skin must resist the pressure, deflections are set up which cause a certain amount of quilting. It is easy to see that if the frames were very heavy their circumferential deflection would be quite small, so that the skin would bulge a good deal. However, if the frames are very light it is to be expected that the frames will deflect and thus decrease the size of the bulges. In Fig. 9 the skin deflection relative to the stiffener is shown as a function of the pressure. The strange and unexpected feature shown in this figure is

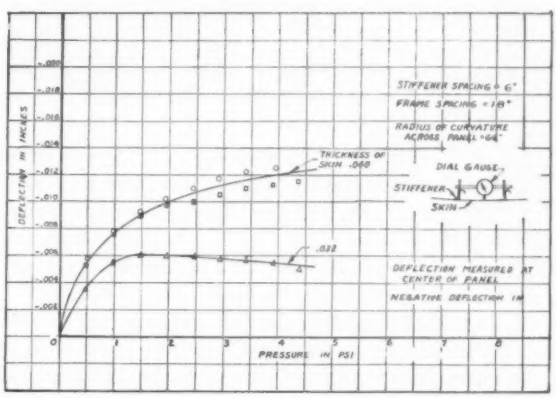

FIG. 9. Skin deflection relative to stiffener as a function of pressure.

that the deflection of the center of the panel relative to the stiffeners is negative, which means "inward." It is also noteworthy that the thicker gage skin deflects inwardly more than the thin one, and in either case the deflection at the center of the panel is small. Part of the negative deflection may be due to the fact that these panels had a slight curvature in the longitudinal direction, but the major portion is due to the skin at the center of the panels (between frames) approaching a polyhedron.

The authors were at first skeptical of this result, thinking it was some local effect or error in the experimental set-up. They were convinced of its validity, however, after several check tests on different panels gave the same result. This effect is undoubtedly dependent on a large number of variables such as skin thickness, stringer stiffness, stringer spacing, frame spacing, frame area, diameter of fuselage, etc. Ob-

viously no generalization can be drawn from this one case.

On the other hand, measurements of the stiffener deflection show that the stiffener deflects outwardly, as one would expect. Fig. 10 shows the deflection at the center of a bay as a function of pressure. The curves in this figure show that the stiffener fastened to the 0.032 skin deflects more than the 0.040 one.

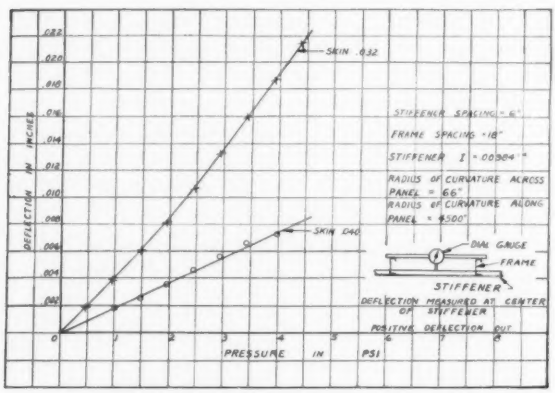

FIG. 10. Skin deflection relative to frame as a function of pressure.

Of course the magnitude of these deflections is a function of the panel size, stiffener size and the frame size. The important thing shown by these tests is that the quilting deflections are small for a reasonable combination of stiffener, frame and panel size.

Another problem is that of the stiffener, frame and skin stresses due to pressure. Again, in the case of a monocoque fuselage the answer is simple, for the skin stresses are given by the two equations,

$$\sigma_L = rp/2t \tag{1}$$

and

$$\sigma_c = rp/t \tag{2}$$

where σ_L = longitudinal stress
σ_c = circumferential stress
r = radius in inches
p = pressure in pounds per sq.in.
t = skin thickness

It might seem logical to assume that if longitudinal stiffeners were added to the monocoque shell they would take as much stress as the skin, since the skin and stiffeners are rigidly fastened together with rivets or spotwelds. This would mean that the average longitudinal stress in the skin and stiffeners would be given by

$$\sigma_L \text{ (Average)} = \frac{Ap}{\textit{Total stiffener area} + \textit{skin area}} \tag{3}$$

where A = cross-sectional area of the fuselage

The above discussion neglects the important fact that the skin has stresses in two directions. Thus, the effect of Poisson's ratio must be considered. Since the skin is subjected to "hoop" tension as well as longitudinal stress, the stresses in the stiffeners and the frames must be determined from a deformation standpoint. The difficulty is that if the circumferential tension in the skin is not known the longitudinal deformation cannot be calculated, and *vice versa*. Since the average circumferential tension is approximately twice the longitudinal tension it can be seen that, due to Poisson's ratio effect, the stiffener stress will be a smaller percentage of the average longitudinal stress than the frame stress will be of the average circumferential. The average circumferential stress is defined as

$$\sigma_c \text{ (Average)} = rpd/(A_F + dt) \tag{4}$$

where d = frame spacing
A_F = frame area

Figs. 11 and 12 show the results obtained on a typical example of present-day construction. Fig. 11 gives the longitudinal stresses as a function of pressure and Fig. 12 gives the circumferential. The center line in Fig. 11 is the calculated average stress given by Eq. (1).

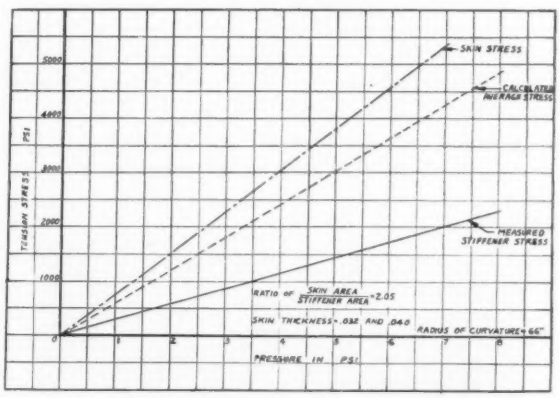
SKIN STRESS
CALCULATED AVERAGE STRESS
MEASURED STIFFENER STRESS
RATIO OF SKIN AREA / STIFFENER AREA = 2.05
SKIN THICKNESS = .032 AND .040
RADIUS OF CURVATURE = 66"
TENSION STRESS PSI
PRESSURE IN PSI

FIG. 11. Longitudinal stresses as a function of pressure.

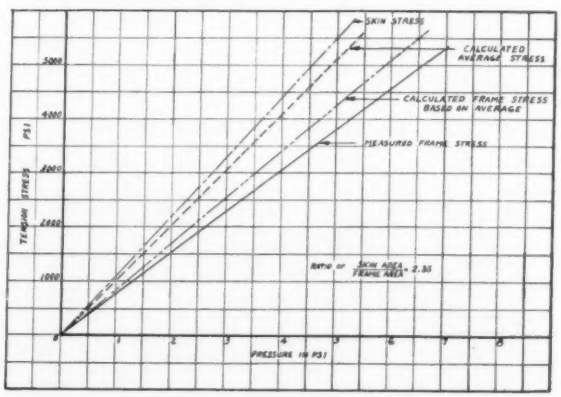
SKIN STRESS
CALCULATED AVERAGE STRESS
CALCULATED FRAME STRESS BASED ON AVERAGE
MEASURED FRAME STRESS
RATIO OF SKIN AREA / FRAME AREA = 2.35
TENSION STRESS PSI
PRESSURE IN PSI

FIG. 12. Circumferential stresses as a function of pressure.

The lower line is the longitudinal stress measured experimentally. It will be observed that this stress is only about one-half of the average.

The measured stiffener stress is checked almost exactly by using

$$\sigma_{stiffener} = \sigma_L \text{ (Average)} - \mu\sigma_c \text{ (Average)} \qquad (5)$$

where μ = Poisson's ratio (For dural $\mu = 0.3$)

Knowing the stiffener stress, the skin stress can be calculated from equilibrium conditions. Fig. 12 shows why there is a small amount of quilting as pressure is applied. The measured frame stress is lower than the calculated value based on the average; thus, the skin deflects more circumferentially than does the frame. The equation used for the calculated value is

$$\sigma_{frame} = \sigma_c \text{ (Average)} - \mu\sigma_L \text{ (Average)} \qquad (6)$$

The results are undoubtedly affected by many parameters but tests indicate, that for skin thicknesses between 0.032 to 0.051 inch and with a ratio of skin area to stiffener area and of skin area to frame area of about 2, the results will in general be the same.

Effect of Pressure on Bending Stresses

The pressure will create stresses as mentioned above but the question is whether the pressure will alter the stresses due to bending. For bending loads low enough so that no skin buckling takes place one would expect that the pressure would have no effect; however, for loads above that the problem must be more carefully considered. Undoubtedly the skin on the compression side would have a higher buckling value and give greater effective width after buckling when loaded with pressure. The change in effective area on the compression side moves the neutral axis and changes the moment of inertia of the section. Thus, the bending stresses due a given load may be quite different with and without pressure.

Fig. 13 shows the experimental results obtained on a fuselage under a given load with and without pressure. The stresses due to load only are given, not the sum of the load stresses plus pressure stresses. It should be mentioned at this point that there is more material on the tension side than there is on the compression side; thus, the large difference between maximum tension and maximum compression stress. It will be noted that the maximum tension stress due to bending is considerably less when pressure is present than when it is not. The curves show that unless the tension stresses due to pressure are more than 2500 lbs. per sq.in. the tension side of the fuselage is no more critical with pressure than without. This effect may have an important effect on skin seams. The bending stresses on the compression side are about the same with and without pressure. The results shown in Fig. 13 are not intended to be taken as representative; they merely indicate that pressure may alter appreciably the stresses caused by a bending load. The amount and manner in which the stresses are changed depends upon the pressure, the magnitude of the load and the distribution of material around the fuselage. In general, it may be said that the compressive bending stresses with pressure will be equal to or smaller than those without pressure, but the tension stresses can be either smaller or larger (usually smaller). If most of the skin which is made more effective by the pressure is near the extreme fiber, the stresses on the tension side will be reduced. However, if most of the skin affected is near the neutral axis the tension bending stresses will be increased.

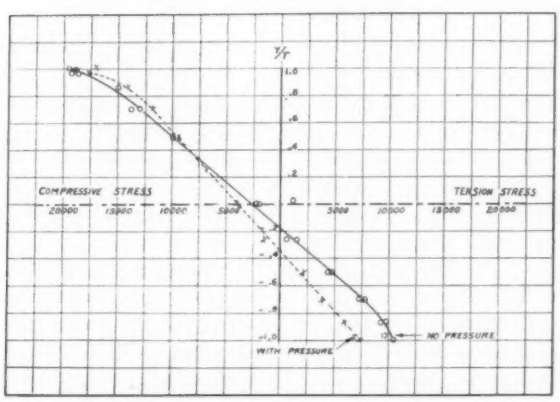

FIG. 13. Effect of pressure on fuselage stresses.

Frame Size

The requirement that the fuselage be as light as possible and that the unobstructed space enclosed by it be as large as possible dictates the use of frames as small as all factors will allow. The two principle functions of a frame are to be able to hold the shape of the structure and to resist and distribute concentrated loads, such as floor, berth and cargo loads. After the concentrated loads have been considered, a large part or number of frames may still be undetermined as to the size required. This means that the strength or stiffness required to hold the fuselage shape becomes a deciding factor.

It is desirable at this point to introduce a discussion of general instability. General instability is defined as the type of failure which will occur in a structure which has frames and longitudinals of such rigidities that both will fail simultaneously under the critical load. In other words, collapse of a fuselage under bending will take place in such a manner as to destroy the load carrying properties of all three structural elements: sheet, longitudinals and frames. The C.A.A. has sponsored a study of this type of failure at the California Institute of Technology.[4]

If the probability of this kind of instability is entirely absent in the fuselage, the frames are for shape purposes unnecessarily heavy or too deep, thus decreasing the

inside diameter of the fuselage. No matter how rigid the frames are made the structure cannot carry a stress greater than that required to buckle the longitudinals between frames. The complete and exact solution for the general instability stress of a curved framework of frames and longitudinals covered with thin sheet is probably unattainable; however, simplified treatments have been developed and experiments conducted which indicate the effects of various parameters. Due to the uncertainty and limited knowledge at the present time on this type of failure it was felt that tests should be made on a representative section if it was to be designed near the region of general instability.

Method of Determining General Instability Stress Experimentally

Since it is impossible at the present time to calculate with a sufficient degree of certainty the general instability stress of a fuselage, it was desirable to develop an experimental method which could be used on a test section. Considerable credit for the following method must be given to the previously mentioned work done at the California Institute of Technology. It was found originally, somewhat by accident, that if a structure was loaded normal to the surface, the amount of deflection for a given normal load was greater when the structure had a compression stress. An investigation of this "effective spring constant" of the structure has been shown to have a direct bearing on the failure stress of the structure. For lack of a better term this "effective spring constant" has been called normal restraint. When the proper parameter is found which will take into account the radius of curvature of the structure and the length over which it is measured, it is suggested that this quantity be called the "normal restraint coefficient."

Panel failure, as well as general instability, can be investigated by this means. Fig. 14 shows a typical example of the type of data obtained from a test performed on a panel between two frames. The general procedure for a panel study is to mount a dial gage on two adjacent frames such that the deflection caused by a normal load at the center of the panel is measured. Various amounts of normal load Q are then placed on the panel at different values of end stress, and the deflection is noted. Upon plotting the value of Q/δ against the stress in the stiffener a straight line variation for low stresses will be obtained. Extrapolating this line to zero normal restraint will give a stiffener stress which the panel cannot exceed. Tests indicate that the panel will actually fail in the neighborhood of 75 to 80 per cent of this upper value. Note the dotted line in Fig. 14.

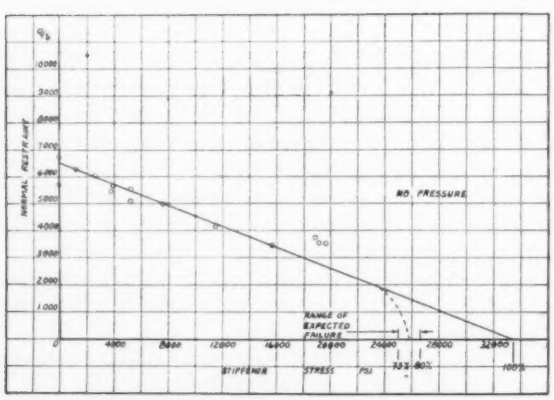

Fig. 14. Normal restraint of a stiffener *vs.* stiffener stress.

In the case of general instability the set-up is made on a larger scale; *i.e.*, the load is placed at a frame and the deflection is measured relative to frames which may be several frames away on each side of the loaded one. Fig. 15 shows the results obtained from an actual test of this type. No experimental point was obtained at failure, due to the fact that the particular construction used failed between frames below that at which general instability was expected. The probable range of failure is indicated on the figure.

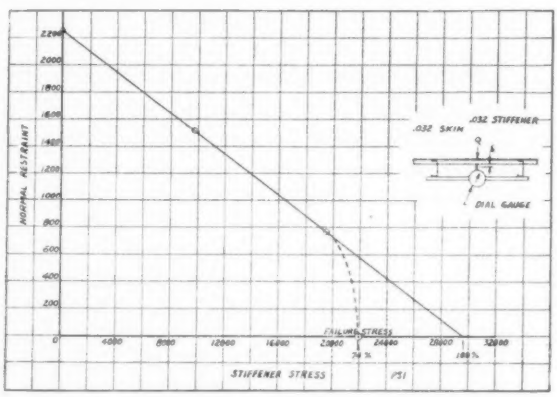

Fig. 15. Normal restraint of a frame *vs.* stiffener stress.

Concluding Remarks

After considerable experience with strain gages of the electrical resistance type, highly satisfactory results have been obtained with this type of instrument. A study of the effect of pressure on a stiffened monocoque structure has shown that Poisson's ratio must be considered when dealing with frame and stiffener stresses. Tests indicate that for pressures below 6 lbs. per sq.in. quilting of the skin is not a serious problem for a circular or nearly circular fuselage. In addition to the stresses caused by pressure alone it was found that the presence of pressure can alter the magnitude of stresses due to bending. This effect is caused by the change in effectiveness of the skin in carrying compression.

Frame size and rigidity in a large airplane should be determined by a careful consideration of two factors: (1) the concentrated loads applied inside the cabin, and (2) the rigidity necessary to preclude general instability. An experimental method is described which will indicate in advance the approximate stress at which either panel failure or general instability will take place. This method is of considerable value for two conditions: (a) if panel failure takes place before general instability the minimum safe value for frame rigidity can be estimated and compared with actual values; and (b) an indication of the load at which general instability will take place can be used to eliminate unexpected failures.

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[5] *Pressure Cabin Investigation*, Air Corps Information Circular No. 710.

Letter to the Editor

October 5, 1940

Dear Sir:

It is gratifying to see increasing publicity given to dimensionless coefficients applied to the solution of column problems. It seems worthwhile to call attention to some previous uses that have been made of some of the coefficients to which Mr. Merriam calls attention.*

The use of α and γ is old and not uncommon; it would be a considerable task probably to trace the origins of these dimensionless quantities. L. B. Tuckerman apparently first introduced 2β in his (unpublished) doctoral dissertation in February, 1921. He made the significant proposal of using α and 2β as non-dimensional coordinates for representing the results of column tests. These variables appeared later in Technical Note No. 307 of the National Advisory Committee for Aeronautics, *Strength of Tubing Under Combined Axial and Transverse Loading*, by L. B. Tuckerman, S. N. Petrenko and C. D. Johnson, Washington, June, 1929. Since 1929 the dimensionless quantities α and 2β have been used in several publications of the National Advisory Committee for Aeronautics and the National Bureau of Standards, and elsewhere.

* *Dimensionless Coefficients Applied to the Solution of Column Problems*, Kenneth G. Merriam; September, 1940, Journal of the Aeronautical Sciences.

The general parabolic or hyperbolic type of formula

$$\alpha = 1 - \frac{2^n + 1}{n}\left(\frac{n}{n+2}\right)^{\frac{n}{2}+1}\beta^n \qquad \text{(a)}$$

and the Rankine formula

$$\alpha = \frac{1}{1 + 4\beta^2} \qquad \text{(b)}$$

have been discussed by the writer in *Column Curves and Stress-Strain Diagrams*, Research Paper No. 492, Bureau of Standards Journal of Research, vol. 9, October, 1932. When $n = 1$ in equation (a), a straight line tangent to the Euler curve is obtained. When $n = 2$, equation (a) represents the Johnson parabola.

Incidentally, it seems preferable to include the factor 2 in β, as greater simplification will usually be obtained by so doing, that is, define β as

$$\beta = \frac{1}{\pi}\frac{l}{r}\sqrt{\frac{s}{E}}$$

Wm. R. Osgood
National Bureau of Standards

Recent Developments in Magnesium Alloys

JOHN C. MATHES

The Dow Chemical Company

ABSTRACT

Increased airplane production and a wider use in each plane have rapidly increased the demand for magnesium alloys. Some of the metallurgical developments and fabrication methods which have helped to make this wider use possible are discussed in this paper.

PERHAPS the most impressive development relative to magnesium during the past year has been the remarkable increase in the demand for it. This is illustrated by the fact that the domestic production by January, 1941, is expected to be approximately four times as great as the rate of production in January, 1940. A new plant now under construction in Texas represents a very interesting development because the process involves the extraction of magnesium from the sea water. In this process, magnesium chloride is first extracted chemically and is then electrolyzed to produce magnesium. Some idea of the vast supply from this source may be gained by a simple calculation based upon the concentration of one part of magnesium per thousand of ocean water. On this basis, each cubic mile of sea water contains over nine billion pounds of magnesium.

While it is true that a large part of this increased production of magnesium is required for metallurgical purposes and for alloying with other metals, particularly aluminum, the increased demand for magnesium base alloys has also contributed substantially to the need for the larger supply. Magnesium alloy consumption for the first quarter of this year was more than twice as great as for the similar period in 1939, and more than eight times as great as in 1938. This increase is due, largely, to increased airplane production. It is more than proportional, however, because the quantity of magnesium alloys per plane is rapidly growing. The direct cause of this is the demand for lighter weight but an indirect cause, and the one which makes the increased use possible, has been the metallurgical developments which have improved the alloys, protective treatments and fabrication practices. It is the purpose of this report to discuss some of these developments.

Much work has also been done in improving magnesium alloy castings.[1] However, the use of these castings is now so general and the methods of fabricating so well standardized, that no mention of this work will be offered, and the discussion will be limited to alloys in the wrought form.

Presented at the Second Annual Summer Meeting, I.Ae.S., Pasadena, California, June 24–26, 1940.

FABRICATION TECHNIQUE

One of the most important considerations which has limited a wider use of magnesium alloy sheet has been the difficulty of working it by the standard shop practices which have been developed for other metals over a long period of years. The development of methods for forming, welding and riveting which are reliable and economical is, therefore, a necessary step in making the advantages of its lighter weight available. Work along this line is constantly in progress, and definite and final conclusions cannot be offered at this time. It is possible, however, to review some of the work that has been done to date, to suggest some of the problems which are met, and to suggest tentative solutions based on this work. The following paragraphs outline some of these conclusions.

Forming

The forming of magnesium alloys is different from the forming of other metals in that all but the most simple operations must be done at elevated temperatures requiring that provision be made for preheating the sheet or dies, or both. The advantages of the hot forming method are that "spring-back" is eliminated and that, in many cases, more severe forming can be done in one operation. The former advantage generally simplifies the die design by eliminating the determination of proper "spring-back" allowance for each job, and the latter advantage often reduces the number of dies required in deep draw work. In fact, one can almost predict that as the manufacturing plants become more familiar with hot forming operations, the advantages of working with "dead" soft and plastic materials will be great enough that the process will be extended to other metals as well.

At the present time, the magnesium—1.2 per cent manganese alloy designated by Army Air Corps Specification No. 11317 or Bureau of Aeronautics Specification No. M-111—is universally used for all formed parts. In the annealed condition, it has the following typical properties:

Ultimate Tensile (lbs. per sq.in.)	32,000
Tensile Yield (lbs. per sq.in.)	16,000
Elongation (per cent)	15

This material is particularly adaptable to hot forming operations, because the physical properties are inherent in the material and are not dependent upon subsequent heat treatment. During the forming operations at elevated temperature, the properties are, of course, reduced, but after the metal has cooled to room temperature, the above properties will again return if the metal has not been overheated. A maximum forming temperature of 750° may safely be used. Because of the fact that the properties are not affected by forming temperatures, as would be the case with a heat treated material, the necessity for subsequent heat treatment and the possibility of attendant warpage or distortion is avoided.

In this discussion of forming operations, the author has eliminated consideration of experimental or hand forming and will consider only production methods for shallow and deep forming.

Flanging, Dimpling and Shallow Draws

Perhaps the most widely used method for comparatively shallow forming is the Guerin process, using rubber as the forming medium. Largely through the experimental work done by the Douglas Aircraft Company, airplane parts of magnesium are now being made in production by these methods. It has been found that magnesium alloys are readily adaptable to this process by the comparatively simple expedient of using heated steel dies. In most cases the dies are heated by electric platen or cartridge heaters and insulated from the bed of the press by Transite or some other insulating material. Where platen heaters are used, it is the general practice to install a "hot plate" on the press which will act as the heating unit for any die placed upon it, while with cartridge heaters, it is sometimes more economical to place them in holes drilled directly in the base of the die itself. For comparatively flat work, where the sheet blank will come in contact with a considerable area of the die, no preheating of the sheet itself is necessary as it will readily absorb heat from the die. If this is not possible, or if the time lag while the sheet is heating prevents efficient operation, a simple portable oven for preheating the material can readily be set up. This is rarely necessary, however, because the heat capacity of magnesium is very low and its thermal conductivity comparatively high. Many of the ordinary forming operations can be done at temperatures of from 250°–350°F. and, for this range, ordinary rubber can be used in direct contact with the sheet. If the operation is so severe as to require higher temperatures, a thin sheet of asbestos cloth may be used to protect the rubber. In this connection, it is also possible that Buna rubber will provide a means of using rubber directly with sheet at higher temperatures.

If a large number of small pieces are to be formed it is often more economical to use steel male and female dies on a small press rather than to use a single steel die and rubber on a large hydro press. In such cases, both of the dies are usually equipped with heating elements and, if the gage of the sheet is nominal, no preheating is necessary even to operate the press at a maximum rate. A similar practice is followed where rivet holes must be dimpled on a production basis, or small holes flanged. Fig. 1 illustrates a simple and inexpensive tool which can be mounted on a small press and which is very suitable for this type of work. Provision is made for heaters to maintain both the male and female dies at from 350°–400°F. At these temperatures the sheet will heat up sufficiently from the dies for the operation to be carried on at the rate of from 300–400 operations per hour as a dwell of 10 seconds is the maximum required for gages up to 0.050 in. In order to prevent radiation losses, the heating elements are wrapped with insulating material and, to permit more flexible operation, the heaters are threaded so that a number of different sized dies can be used with the same heater. Experience has shown that this tool can be heated up, ready for use, in about ten minutes and that, if the dies are changed while the element is hot, a period of five minutes is sufficient to heat the dies alone. If provision is made for preheating the dies before changing, this time loss can also be avoided. The tool illustrated in Fig. 1 has no device incorporated for stripping the sheet from the

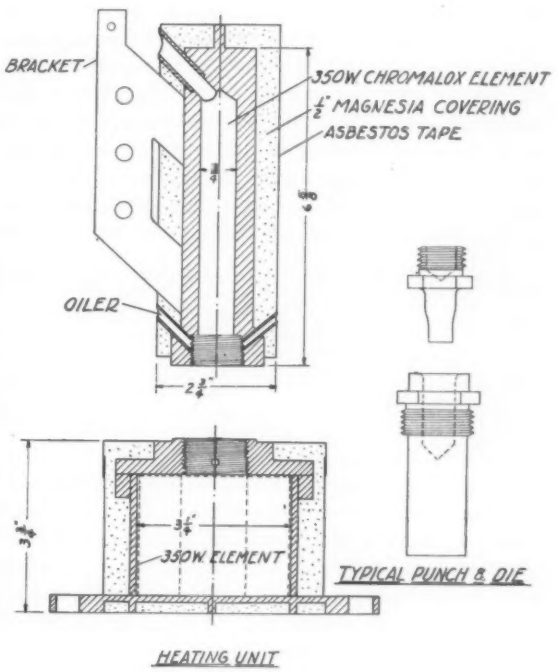

FIG. 1. Dimpling and flanging tool.

male die, and it is probable that such an accessory would be desirable. Suitable dies can also be installed in this heater for dimpling sheet for Dzus fasteners.

Deep Drawing Operations

The development of suitable procedure for the deep drawing of magnesium alloy sheet has been a very definite step forward as it made possible the production of parts for which there was a waiting demand. Such parts included airplane wheel caps, fairings, and dust covers, junction boxes, oil tank heads, etc. Many of these parts can be spun but the drawing of them seems to be a more economical method because, although the die cost is greater, the rate of production is much faster.

In developing this process, the established practices for the drawing of steel were followed as closely as was practicable, using the customary punch, pressure pad and female die. This had the advantage of giving to the industry a process with which they were already familiar and a die design practice which was also very similar. There are, however, three essential differences between the magnesium practice and the steel practice:

(1) The operation is done at elevated temperatures of from 500° to 750°F.
(2) It is possible to make parts in a single operation which would require two or three draws in steel.
(3) Controlled speeds, either by the use of hydraulic presses or of mechanical presses with controllable speeds, are necessary.

The die expense is minimized because fewer operations are required and, in most cases, but a single die is needed for even the deepest of draws. Cylindrical cups with depths of $1^1/_2$ times the diameter and square boxes with depths equal to the side dimension are readily made. As against a 30 to 45 per cent range of reduction for single draws in steel

$$\left(\frac{\text{diameter of blank} - \text{diameter of cup}}{\text{diameter of blank}}\right)$$

it is possible with magnesium to make reductions of 60 per cent or even greater. The experience to date with this process has indicated the advisibility of the following practices:

(A) Die Design.
  (1) Dies should be designed on the basis of greater per cent reduction than is customary with steel.
  (2) For the female die, a minimum entering radius of 4 to 6 times the sheet thickness should be used. A radius as large as $8t$ is desirable if possible as, generally, the larger the radius, the easier the operation.
  (3) Ordinary mild steel boiler plate is satisfactory for both the draw ring and pressure pad. Die steel is not necessary for the production quantities ordinarily encountered in aircraft work.
    (a) For large diameters it is sometimes desirable to anneal the plates to prevent warpage at the elevated temperatures but this is not often necessary.
  (4) A smooth sliding surface on the draw ring and pressure pad should be provided.
    (a) On small sizes, these surfaces should be finished as smooth as possible on a lathe and then polished with fine emery cloth.
    (b) On large sizes, or for shallow draws, the machining operation is not often necessary and the surfaces need only be disc ground and then polished with emery cloth.
    (c) After polishing, the surfaces should be well lubricated by rubbing in "Rotojector" lubricant or a 20 per cent graphite-tallow solution on both the pressure pad and female die.
  (5) It is only necessary to provide for a light holder pressure.
    (a) Ordinary C clamps are satisfactory for experimental work or small quantities.
    (b) Air cylinders are suitable for single acting presses.
    (c) The secondary stroke is suitable with double acting presses.
  (6) The punch, or male die, can be made of steel, aluminum or magnesium.
    (a) It is not necessary to polish or lubricate the punch.
    (b) Magnesium is not suitable for temperatures over 400°F.
    (c) On light alloy punches, several studs are required as there is a tendency for them to pull out at the elevated temperatures.
    (d) Steel or aluminum punches must be designed to correct for the elevated temperature operation.
  (7) Steel is used for the female dies and they must be designed to correct for the elevated temperature operation.
    (a) The coefficient of expansion of magnesium is higher than for steel and it is necessary to compensate for this. (See Fig. 2.)
    (b) The dimension of the finished magnesium part will be smaller than the cold dimension of the steel die.
    (c) Provision should be made, generally, for a temperature rise of 600°F.
      (1) This compensates for a forming temperature of from 600° to 700°F.
  (8) Means of heating the die and pressure pad must be provided.
    (a) Gas ring burners are generally the quickest and most economical method of providing heat.

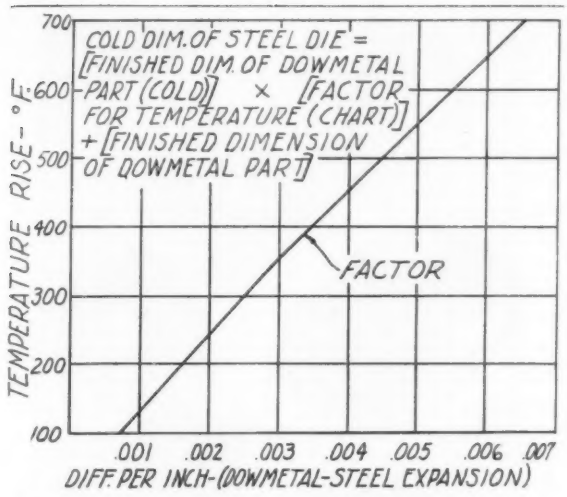

FIG. 2. Temperature conversion chart for steel forming die dimensions.

(b) The ring burners should be located about $^5/_8$ in. to $^3/_4$ in. from the die parts.
(c) For the burners No. 40 holes at $^1/_2$ in. centers are satisfactory.
(d) Low pressure gas should be used.
(e) Thermocouples in both plates to check temperatures are required.

(9) It is generally not necessary to provide for heating the punch, or male die.
(a) On small dies the punch will take up sufficient heat from the draw ring and female die.
(b) Heating of the punch is sometimes necessary on large diameter dies to prevent chilling at the center of a large expanse of sheet.

(10) Clearance of metal thickness plus 0.004 in. to 0.008 in. between punch and die to allow for thickening of the sheet at the end of the draw should be provided.

(B) Forming Practice.

Although the actual forming operations cannot be standardized as closely as the die-design practice, there are certain general steps which can best be followed. Before putting the sheet blank in the press, it should be lubricated with a fine film of grease on each side to make the drawing operation easier and to prevent pick-up. The same type of grease is used for this as is used for lubricating the dies. The die, pressure pad and punch should be brought to the minimum temperature that will do the job. This may have to be determined by trial, but will usually be about 650°F. As mentioned in the comments on die design, it is rarely necessary to provide separate heating elements for the punch because it will pick up sufficient heat from the other parts of the die. In fact, it is sometimes necessary to provide an air blast for cooling the punch as it is good practice to keep it about 200° cooler than the sheet and draw ring. By this means, the sheet has the maximum plasticity during the actual forming operation but is chilled immediately thereafter in order to increase its tensile strength for pulling the balance of the metal through the die without tearing. On small work the sheet will also absorb heat readily from the die and need not be preheated. It is sometimes necessary, however, to preheat large blanks in order to prevent warping and to avoid a time lapse while the sheet is heating up.

The pressure pad should be adjusted to the minimum pressure that will prevent buckling when the punch begins to press the sheet through the die. The proper pressure can only be determined by trial. The press itself should be operated at a slow, steady speed of about 15 ft. per minute. The principle here is to get the sheet moving right and then to keep it going until the operation is completed. Such practices or "tricks" as roughening parts of the die or not greasing certain areas of the blank in order to vary the friction pressure at critical points on square or odd shaped pieces can often be followed to advantage on difficult jobs. There may be some pick-up of metal on the dies, necessitating that the operation be stopped occasionally to clean them. After the sheet is formed and removed from the press, it should be cleaned in a hot chromic acid solution of 10 to 20 per cent concentration in order to remove the graphite lubricant.

With the above operations, it is possible to obtain reasonably close tolerances. On cylindrical cups, for instance, the tolerances for the hot forming operation can be held within ± 0.1 per cent of the diameter. If a closer tolerance is required, the hot drawing operation may be followed by a cold sizing operation. By this means, the tolerances can be held to within ± 0.04 per cent of the diameter. The cold sizing tools consist of a punch and die, similar to those used for the forming but with the die turned slightly undersize and the plug forcing the piece completely through it. On the return stroke, the die ring then acts as a stripper.

As an illustration of the tools used in this process, Fig. 3 shows the cross-section of a die for forming airplane wheel hub caps and Fig. 4 shows a photograph of the same die. The essential parts, as described above, are shown on the section. The shields around the air cylinders should also be noted as they act to keep the heat from these cylinders.

The finished diameter of this hub cap is 4.116 in. $^{+0.003}_{-0.000}$ with 0.062 in. wall. The forming dies were designed to produce a diameter of 4.131 in. with 0.072 in. wall, as a cold sizing operation was necessary to obtain the required tolerances. The diameters of the punch and die are given in Fig. 3 and it should be noted

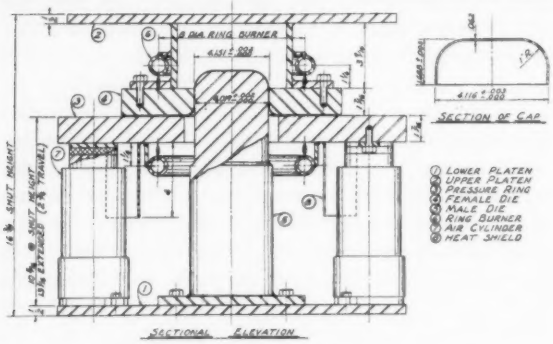

FIG. 3. Section of airplane wheel hub cap drawing die.

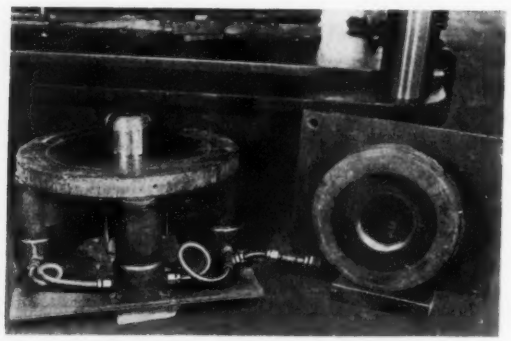

FIG. 4. Airplane wheel hub cap die.

FIG. 5. Typical small parts from magnesium sheet.

that, to compensate for the difference in thermal expansion between magnesium and steel, the cold dimensions of the die are larger than the cold dimensions of the cap. For bringing the caps to exact dimensions, the sizing dies had the following dimensions.

Male	3.9896 in. diameter
Female	4.1056 in. diameter

These produced the necessary tolerances of 4.116 in. $^{+0.003}_{-0.000}$. It should be noted here that the diameter of the female sizing die is not only less than the diameter of the finished part but that the clearance between the male and female die is 0.004 in. less than the final thickness. The production rate for this part was approximately 100 per hour for the forming operation and 200 per hour for the sizing operation.

Some other small parts formed by this process are illustrated in Fig. 5 while some larger wheel fairings and dust covers are illustrated in Fig. 6. The deepest cylindrical cup shown in Fig. 5 is $4^3/_4$ in. diameter by $4^3/_4$ in. deep by 0.050 in. thick. It was drawn from a $11^1/_2$ in. diameter blank and has a $^1/_4$ in. radius at the bottom. The rectangular box shown in Fig. 5 is $4^1/_2$ in. by 4 in. by $4^1/_2$ in. deep. It was drawn from 0.032 in. stock and has a $^1/_4$ in. radius at the corners and bottom. The sides of the finished piece are 0.028–0.029 in. thick at the bottom and 0.032 in. thick at the top. The large dust cover in Fig. 6 is $43^1/_4$ in. in diameter and is made of 0.128 in. material. The drawn portion is 4 in. deep and has a $^1/_8$ in. radius at the bottom.

In the above discussion, some of the principal considerations regarding deep drawing operations have been outlined although complete data on all of its features are not available. It has been observed, however, that thin material is somewhat harder to form than thicker material and that the limits of maximum draws will decrease with thinner gages. It has also been found that the bottom radii should be made as liberal as

FIG. 6. Magnesium alloy wheel fairings and dust covers.

possible because sharp radii tend to give a punching, rather than a forming, action. Increasing the bottom radii aids in the drawing operation up to the point where a radius of from six to eight times the sheet thickness is reached, after which there is no apparent advantage in further increase. Another general conclusion regarding this forming process is that comparatively slow moving presses with closely controllable speeds are best suited and, for this reason, hydraulic presses are more readily adaptable than toggle presses. The rapid action of the ordinary toggle presses as used for stamping work makes them unsuitable for forming magnesium as it is sometimes difficult, or impossible, to sufficiently retard such mechanical presses. Furthermore, the crank action of the toggle press necessarily produces the maximum vertical speed at the beginning of the forming operation and a constantly decreasing speed throughout the remainder of the stroke, whereas the most favorable cycle for magnesium is a slow, steady stroke throughout.

Within certain limitations, this drawing process appears to be an economical method of producing various kinds of formed parts having comparatively regular outlines, providing they do not have "back-draft" or under cuts on the sides or bottom. Even in such cases, it is sometimes economical to do the major forming in this way and to finish the piece in separate dies or by hand. If it is necessary to form irregular contours in the bottom surface during the drawing operation, this can readily be accomplished by substituting a complete female die for the simple draw ring. In this event, the operations and practice are essentially the same as described above for straight draws.

Gas Welding

Research is underway to determine the best practices and details for gas welded joints. The general technique of welding is fairly well established and is well covered by the existing handbooks of The Dow Chemical Company and the American Magnesium Corporation. The current work is on methods of controlling warpage or distortion which may be caused by the high coefficient of thermal expansion and on the comparative fatigue values of various types of butt joints. This work is still too tentative to permit definite conclusions being drawn but the following may be of interest and value:

(A) Preventing Warpage or Distortion.

The experimental work has indicated that this problem can best be controlled by one or more of the following practices:

(1) By providing a rolled bead near the welded seam.
(2) By the use of moist asbestos powder "heat dams" to confine the heat to the welded areas.
(3) By preheating the assembly after "tacking" and prior to final welding.

Many assemblies, of course, do not raise these problems and are readily welded without encountering them.

(B) Relative Fatigue Value of Butt Welds.

The relative fatigue values of various types of welds are indicated by Fig. 7 which, however, is not based on a sufficient number of specimens to be final. These simple tests do not take into account the possible strain relieving value of the beads or flanged welds and represent unrestrained welding conditions. Additional tests are now being conducted to determine the effect of restraint on these relationships.

FATIGUE OF WELDED JOINTS
.040" DOWMETAL MA SHEET

TYPE OF WELD	DEFL.	REVERSALS TO BREAK	DEFL.	REVERSALS TO BREAK
	.400"	1,388,000	.800"	97,000
	.400"	NO BREAK®	.800"	226,000
	.400"	NO BREAK®	.800"	171,000
	.600"	NO BREAK®	.800"	251,000
	.400"	NO BREAK®	.800"	661,000
SPOT WELDS	—	———	.800"	311,000

®AT 20,000,000 REVERSALS

Fig. 7. Comparative fatigue strengths of torch welded seams.

Higher Strength Structural Alloys

Up to the present time, the use of magnesium alloy sheet or extrusions in aircraft construction has been limited to secondary, or comparatively non-stressed parts, which did not require the use of high strength materials. However, serious consideration is now being given to the construction of control surfaces, fuselages, and wings, and to meet this demand higher strength alloys have been developed, both for sheet and extruded shapes. As an indication of this interest, tests were made last year at Wright Field on Magnesium alloy monocoque fin construction[2], and contracts have been awarded for the construction of magnesium alloy wing panels both for static and flight test. In line with this interest, tests on sheet-stringer panels and corrugated sheet are being run in order that data will be available on this subject. A rather complete pre-

liminary design of outer wing panels for one of the Army trainers was made, based on these early tests. This design showed that magnesium alloy wing panels of the same type of construction as the present panels should produce a weight saving of 14 per cent.

The two new alloys which were utilized for this wing design have the following typical properties:

Alloys Properties

	Tensile Strength (Lb. per Sq. In.)	Yield Strength (Lb. per Sq. In.)	Elongation (Per Cent)
Hard Rolled Dowmetal J-1 Sheet	45,000	35,000	8
Extruded Dowmetal Z*	55–60,000	40–45,000	5–10

* Heat treated and aged

Dowmetal J-1 sheet has the same composition as the extrusion alloy covered by Navy Spec. M-314, Grade 1 and Army Spec. 11320. It is characterized by a salt water corrosion resistance as good as the Dowmetal M sheet covered by Spec. M-111 and 11317 and in addition has superior physical properties. The Z Alloy combines the highest physical properties yet obtained in magnesium alloys with acceptable salt water corrosion resistance. The value of the higher strength alloys is shown in Tables 1, 2, and 3, which compare these new alloys with present alloys in flat end compression tests.

TABLE 1

Comparison of Extruded Bulb Angles in Compression

Section	Area (Sq. In.)	Length (In.)	Total Load (Lb.) M-314, Grade 1	Z Alloy
Bulb Angle	0.083	4	1230	1850
Bulb Angle	0.083	6	1035	1510
Bulb Angle	0.143	4	1855	3910
Bulb Angle	0.143	6	1820	3260

TABLE 2

Comparison of Sheet Materials on Sheet-Stringer Panels in Compression

(All Stringers Dowmetal Z Alloy)
(Panels 15 in. Wide—3 Stringers)

Total Effective Area (Sq. In.)	Sheet Thickness (In.)	Length (In.)	Total Load (Lb.) Sheet Material M-111 (Hard-Rolled)	J-1 (Hard-Rolled)
0.903	0.064	15	24,400	27,000

In conjunction with the above compression tests, some work was done on the proper proportioning of extruded magnesium alloy sections in order to get the maximum unit stresses. It was found that the present aluminum alloy sections are not necessarily the most efficient for magnesium, and that the b/t ratios for bulb angles and the proper size of the bulb to stabilize the outstanding legs must be in different proportions. On the basis of the work to date, the following buckling stresses may be expected in the testing of sheet-stringer panels fabricated of hard-rolled Dowmetal J-1 sheet and properly proportioned Z alloy stringers:

TABLE 3

Comparison of Stringer Materials on Sheet-Stringer Panels in Compression

(All Sheet Dowmetal J-1 Alloy, Hard Rolled)
(Panels 15 in. Wide—3 Stringers)

Total Effective Area (Sq. In.)	Sheet Thickness (In.)	Length (In.)	Total Load (Lb.) Stringer Material M-314, Grade 1	Dowmetal Z
0.483	0.051	15	9,875	12,385
0.483	0.051	21	8,025	9,275
0.798	0.064	15	21,800	24,900
0.798	0.064	21	16,250	20,800

Buckling Stresses

Type of Stringer	Area/ Stringer	Sheet Gage (In.)	Buckling Stress* for 15 in. Rib Spacing (Lb. per Sq. In.)
Bulb Angles	0.178	0.064	27,000
Bulb Tees	0.994	0.064	34,000
Bulb Zees	0.193	0.040	32,000

* Unit stresses figured on the basis of total stringer area plus effective skin area ($1.7t\sqrt{E/fc}$).

These stresses should be multiplied by a factor of 1.5 to compare them directly with aluminum alloy on an equal weight basis. The allowable, or buckling, stress of stringers in compression varies greatly depending upon the stringer area. This relationship for Dowmetal Z stringers has been shown by E. W. Conlon.[3]

Further evidence of the importance of the proper proportioning of extruded sections is indicated by studies of the action of magnesium alloys in compression. These have shown the difficulty of preparing reliable column curves based on $1/r$ ratios and is particularly true of magnesium alloys because of their comparatively low modulus of elasticity. It has generally been the practice to use the same column curves for angle, I-beam, bar, channel, or tube column sections on the assumption that theoretically the $1/r$ relationship should be the same for all properly proportioned sections. Practically, however, this is not the case, as it is not always possible to design sections in which each part is fully stabilized, particularly if the section must also be proportioned to permit ready fabrication. Thus, the form factor of the section becomes almost as

variable a consideration as the $1/r$ ratio, and for practical purposes column curves are applicable only to like sections. This is illustrated by the compression test results shown in Fig. 8.

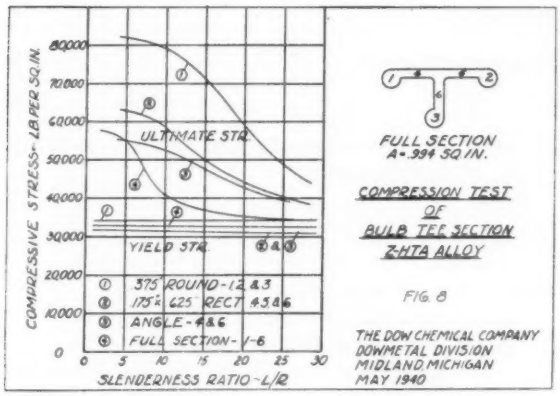

FIG. 8. Compression curves for various extruded sections.

In this test, various types of sections were cut and tested from the same parent extrusion. As will be noted, the compressive yield strengths were approximately the same in all cases, but the ultimate strengths gave widely different $1/r$ curves depending upon whether the sections were tees, rounds, angles, or bars.

New Chemical Treatments

Newer chemical treatments have been developed which greatly improve the salt water corrosion resistance of magnesium alloy sand castings over that provided by the chrome pickle or alkaline dichromate treatments which have been standard for many years. These newer treatments are now widely used and are covered by Army and Navy specifications. By their use, the corrosion rate of cast Dowmetal H panels as determined by alternate immersion in salt solution (3 per cent NaCl at 95°F.) is from $^1/_5$ to $^1/_{10}$ as great as with the previous chemical treatments.

High Purity Alloys

The development of methods for reducing impurities in magnesium alloys has been an outstanding accomplishment and has led to the production of wrought alloys having very superior corrosion resisting properties. These high purity alloys are now covered by Army and Navy specifications which limit the iron and nickel content to a maximum of 0.005 per cent each. By this means, the corrosion rate of untreated specimens of extruded Dowmetal J, for instance, subjected to alternate immersion in 3 per cent NaCl solution is reduced from a range of 5.0 to 15.0 mg. per cm.^{2} per day to a range of 0.2 to 0.5 mg. per cm.^{2} per day. It is also interesting to note that the inherent corrosion resistance of the metal itself has a direct bearing on the comparative protection offered by various chemical treatments. Thus, the comparative values of the old and new chemical treatments on high purity extrusion alloys would not show the wide range evidenced for the casting alloys in the previous paragraph and all would approach the best. With alloys of high purity that possess a low inherent corrosion rate, more complicated treatments involving several steps in application do not show any particular improvement over a simple chrome pickle.

References

[1] Grant, L. B., *Production of Magnesium-Alloy Aircraft Parts*, S.A.E. Journal, Vol. 47, No. 2, pages 325–331, August, 1940.

[2] Air Corps Technical Report No. 4530.

[3] Conlon, E. W., *Magnesium for Aircraft Construction*, Journal of the Aeronautical Sciences, Vol. 7, No. 6, pages 252–255, April, 1940.

Elastic Stability Design Charts for Duraluminum Channels in Compression

JOHN C. SILLIMAN
Pacific Railway Equipment Co.

SEVERAL design charts to aid the engineer in quickly obtaining the "optimum" dimensions of a channel to carry a specific load in a certain confined space have been constructed. The charts are graphical plots of several of the well known elastic stability formulas giving the ultimate load for a thin metal sheet in compression with, first, both longitudinal edges simply supported, and, second, one edge simply supported and one edge free.

Review of Formulas

For a clear conception of how the charts were evolved, the formulas for the two given conditions mentioned above will be reviewed:

(a) For a flat sheet under a uniform compressive load with one edge free and the other simply supported, when the length of the sheet is more than several times its width, the "critical" stress of the element is given by Timoshenko[1] as:

$$\sigma_{cr.} = KE(t^2/b^2) \tag{1}$$

where t = sheet thickness in inches;
b = sheet width in inches;
E = modulus of elasticity in lbs. per sq.in.;
K = 0.412 for the conditions stated above.

From certain tests[2] made with members having free flanges this value of K was found to be somewhat high, and a value of 0.385 is recommended. It has further been determined that when this $\sigma_{cr.}$ value is reached, the sheet is not capable of carrying further load. This expression then gives the ultimate stress for the support conditions assumed.

(b) When the given sheet has both edges simply supported and a length several times its width, Eq. (1) also expresses the "critical" stress, where t, b and E are as given above, and K is theoretically 4.0.

After the sheet has exceeded its "critical" stress it has been found that the central portion of the sheet becomes relatively ineffective, but the edges of the sheet, because of their simple support, will continue to carry an increasing stress (reference 1, page 395). The total value of the two effective widths is expressed by the following formula:

$$b_e = C\sqrt{E/\sigma_{y.p.}}\,t \tag{2}$$

where t = sheet thickness in inches;
b_e = the "effective" sheet width in inches;
E = modulus of elasticity in lbs. per sq.in.;
$\sigma_{y.p.}$ = yield point stress of the material in lbs. per sq.in.;
C = a constant, theoretically 1.9, but in practice usually assumed to be 1.7.

Explanation of Design Charts

For estimating the allowable compressive stress of a channel section, if it is assumed that the web and the flange offer each other mutual simple support, and if it is also assumed that both the flange and the web each reach their ultimate stresses before the channel fails completely, the maximum load of the channel is computed by adding the loads that each element is carrying at its ultimate stress. Further, the allowable stress of the channel as a whole may be figured by dividing the total load of the sum of the elements by the overall channel area.[3, 4]

From Eqs. (1) and (2) expressions suitable for plotting can be derived for $P = bt\sigma$, the ultimate load for each element.

(a) For a flange

$$P = 0.385E(t^3/b) \tag{3}$$

where P = ultimate flange load in pounds;
E = 10,300,000 lbs. per sq.in.;
b and t are as for Eq. (1).

As this formula merely expresses the stability of the elements, it makes no allowance for the yield point of the material. So if the flange critical stress so computed is above the compressive yield point of the material, the ultimate flange load is:

$$P = bt\sigma_{y.p.} \tag{4}$$

Chart I, Fig. 1, is a graphical plot of Eqs. (3) and (4) for several thicknesses of metal in common use in aircraft structures.

Presented at the Second Annual Summer Meeting, I.Ae.S., Pasadena, California, June 24–26, 1940.

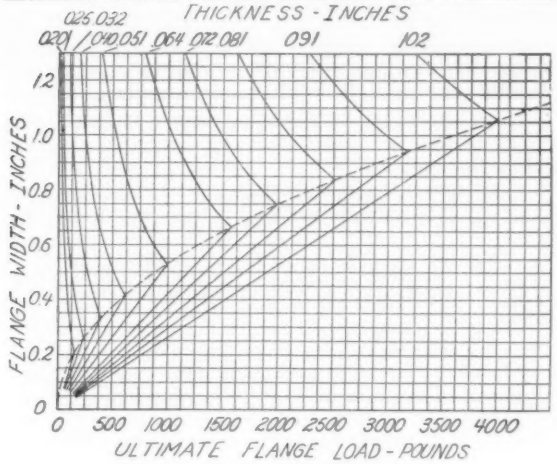

FIG. 1. Channel flange ultimate load.

(b) For the web

$$P = 1.7\sqrt{E\sigma_{y.p.}}t^2 \tag{5}$$

and when $b_e \leqq b$,

$$P = bt\sigma_{y.p.} \tag{6}$$

where P = ultimate web load in pounds;
E is as above;
b_e = "effective width" in inches.

Chart II, Fig. 2, is a plot of Eqs. (5) and (6) similar to Chart I.

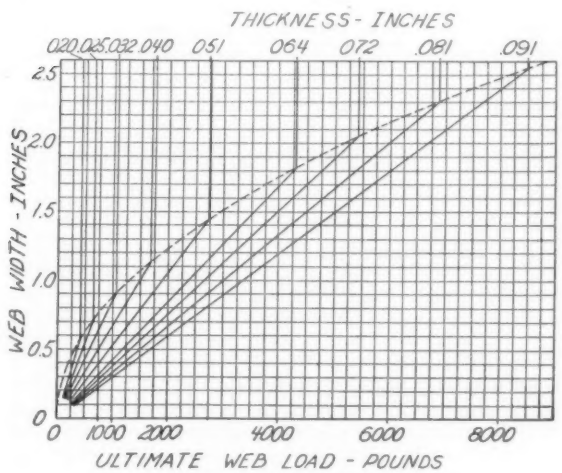

FIG. 2. Channel web ultimate load.

EXAMPLE

Given a 24-STAL channel, Fig. 3, assumed to have support in two directions so that it will not fail as a column.

From Figs. 1 and 2:

P flange = 725 lb.
P web = 2740 lb.

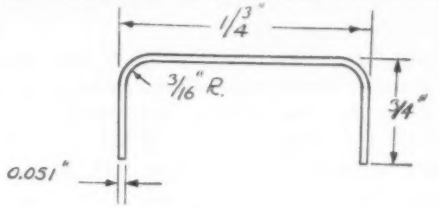

FIG. 3.

It is conservative to compute the channel area from the "mid-line dimensions" as follows:

$$A = 2[(0.750 - 0.051/2)0.051] + (1.75 - 0.051)0.051$$
$$= 0.161 \text{ sq.in.}$$

Ultimate allowable channel stress is: $\sigma_{Ult.} = 4190/0.161 = 26{,}000$ lbs. per sq.in.

It is possible to use Charts I and II for other more complicated sections, provided the necessary edge support between elements of the sections is present. Since these charts are based on a particular set of values for the coefficients K, Young's Modulus E, yield point stress, $\sigma_{y.p.}$, etc., they are not applicable in all cases. Similar charts can obviously be prepared, based on other coefficients or material properties and the author has found them very useful for design in stainless steel.

GENERAL DISCUSSION OF METHOD

The limitations and accuracy of these charts may be checked by the designer as various channel sections are tested in compression.

The author believes that while the web and flange of a channel are rigidly connected to each other under load, the edge condition is that of "simple support." If the flange buckles at a lower stress than the web, the outward movement of the flange will produce a moment acting on the web at the point of mutual support. (Ref., Fig. 4.)

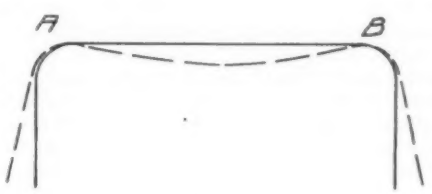

FIG. 4.

The flange buckles, but still carries its design load much the same as a Euler strut. As it buckles, more load is transferred to the web. The web finally buckles and reaches its ultimate allowable load. At this point the channel has reached its ultimate load. In this process, the channel has rotated about the points A and B in Fig. 4; thus, qualitatively speaking, while the flange and web are mutually fixed, this pivoting action prevents the development of "fixed support" be-

tween the elements, so that the conditions assumed in Charts I and II are fulfilled.

If the channel dimensions are such that either the channel or web buckles and will not maintain its design load before the other element has reached its design load, then the design charts will not give the true ultimate allowable channel load. In many cases, however, the chart will give the "crippling load," which can be reduced by the procedure of Art. 10:9 of reference 3 to determine the allowable load. The limitations of the charts will be established as test data become available.

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[1] Timoshenko, S., *Theory of Elastic Stability*, first edition, McGraw-Hill Book Co., New York and London, pages 339 and 331, 1936.

[2] Trayer and March, *The Elastic Instability of Members Having Sections Common in Aircraft Construction*, N.A.C.A. Technical Report No. 382, 1931.

[3] Niles, Alfred S., and Newell, Joseph S., *Airplane Structures*, second edition, John Wiley & Sons, New York, Vol. I, page 293, 1938.

[4] Air Corps Tech. Report No. 4313, Section 2, pages 1 and 6; Air Corps Materiel Division, Wright Field, Dayton, Ohio, May 4, 1937.

Letter to the Editor

August 12, 1940

Dear Sir:

The design curves of Silliman presented on page 33 of this issue of the Journal came to the writer's attention while he was engaged in conducting the tests for an Engineer's thesis at Stanford University.* The problem was that of satisfactorily correlating the theoretical and experimental ultimate column loads on thin steel building studs. The specimens were of two different cross-sectional shapes, namely: channel section and "Cee" section. The Cee was merely a channel with lips on the flanges. The thickness was varied from United States Standard 20 gage (0.0368 in.) up to 14 gage (0.0766 in.). Consistent with aeronautical engineering practice these sections may be analyzed as a series of flat plates under edge compression. The web of both sections and the flanges of the Cee are assumed to be simply supported along two edges; the flanges of the channel and the lips of the Cee are assumed to be simply supported along one edge and free on the other.

A set of curves such as those described by Silliman might readily be used in the design of studs similar to those tested for the thesis referred to above. It was originally intended to draw up such a set using physical constants in the basic equations which would be appropriate for the steel at hand. However, upon running tensile tests on coupons cut from damaged specimens, it was found that, while within any one gage the yield point was fairly constant, the yield points of the various gages diverged greatly. Also there was a vast difference in yield strength between the specimens furnished by two different steel companies. The actual range encountered was 21,100 to 41,800 lbs. per sq. in. If curves similar to Silliman's were to be designed to cover this range of yield points, it would be necessary to have either a large number of curve sheets for both web and flange or to have a large number of curves on one sheet. Either of these schemes would be confusing and difficult to handle. To eliminate this difficulty the curves shown in Figs. 1 and 2 were designed. For the web design curve, Fig. 1, the parameter $\sqrt{\sigma_{y.p.}/1000}$ was introduced. The actual web width is multiplied by this parameter and the load scale is divided by the same quantity. After observing the indicated operations, the curve is used in the same manner as Silliman's web design curve.

The curve for flange design, Fig. 2, has a family of critical curves for different yield points rather than the one critical curve Silliman shows. The critical curve is that curve below which all thicknesses of material are wholly effective in carrying load and above which all thicknesses are only partially effective (for example, see curve AB). It is not necessary to modify

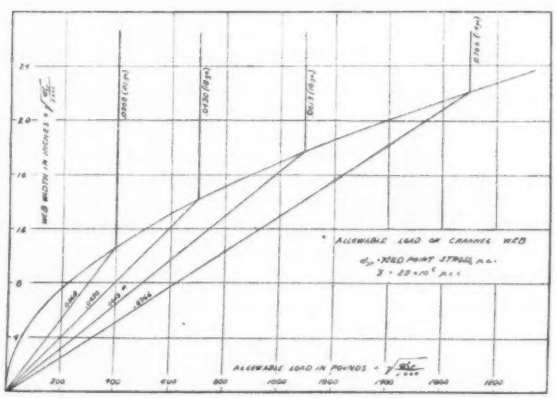

FIG. 1.

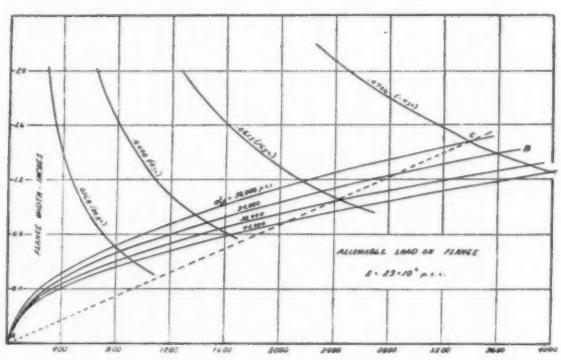

FIG. 2.

either the flange width or the allowable load to use this flange design curve. Once the yield point of the material is known, the curve is used in exactly the same manner as the curve shown in Silliman's Fig. 1. To avoid confusion, the straight portions of the curves for each gage are omitted. For any particular case, a straight edge may be laid from the origin to the intersection of the gage in question with the appropriate critical curve (for example, along line AC).

JOSEPH S. DUNNING
Douglas Aircraft Company

* Dunning, J. S., and Rieben, T. R., *An Experimental Investigation of the Strength Properties of Lightweight Steel Studs*, Thesis submitted as partial fulfillment of the requirements for the degree of Engineer, Stanford University, California, March, 1940.

Institute Notes

Glenn L. Martin to Receive Daniel Guggenheim Medal

Glenn L. Martin, President of The Glenn L. Martin Company, has been selected to receive the Daniel Guggenheim Medal for 1940. Elmer A. Sperry, Chairman of the Board of Award, announced that Mr. Martin had been chosen as the recipient of this honor "for contributions to aeronautical development and the production of many types of aircraft of high performance." The Daniel Guggenheim Medal is presented annually "as an award for notable achievement in the advancement of aeronautics." The Board of Award is composed of nine members designated by the American Society of Mechanical Engineers, the Society of Automotive Engineers, the Institute of the Aeronautical Sciences, and former American recipients of the Medal. The recipients of the Medal are chosen by this Board and international representatives from England, France, Germany, Holland, Italy, and Japan.

Mr. Martin is an Honorary Fellow and past president of the Institute of the Aeronautical Sciences. He has been a manufacturer of airplanes since 1909, in which year be built his first airplane and taught himself to fly. For many years he was one of the best known pilots in the United States. He has built many types of aircraft, notably bombing planes and clipper flying boats used on the transpacific air routes. He received the Collier Trophy in 1932. Mr. Martin was born in Macksburg, Iowa, in 1886 and attended Kansas Wesleyan University. He received the honorary degree of Doctor of Science from the University of Maryland in 1937.

Presentation of the Medal and the certificate of award will be made at the Honors Night Dinner of the Institute on January 28, 1941.

Honors Night Dinner to Open Ninth Annual Meeting

The 1941 Honors Night Dinner of the Institute will be held on the evening of Tuesday, January 28th, at the Biltmore Hotel in New York. It will be the opening session of the Ninth Annual Meeting, the technical sessions of which will follow at Columbia University on January 29th, 30th, and 31st.

As in previous years, the officers of the Institute for the coming year will be inducted. The Sylvanus Albert Reed Award, the Lawrence Sperry Award, the Daniel Guggenheim Medal, Fellowships in the Institute and other honors will be presented. The program of this evening, which is the Institute's outstanding annual social function, will be concluded with an address by a distinguished guest.

Since the programs for the various technical sessions of the Ninth Annual Meeting are being arranged, it is requested that anyone who intends to submit a paper to the committee but has not yet sent in an abstract should do this immediately in order that the committee may have an opportunity to consider it.

Dinner to Wright Brothers Lecturer and Simultaneous Meetings on December 17th

On December 17th a dinner to honor Dr. Sverre Petterssen, the Wright Brothers Lecturer for 1940, will be held at 6:30 p.m. at the Men's Faculty Club of Columbia University in New York. Institute members and their friends are invited to attend. Reservations should be made in advance at Institute headquarters.

Following the dinner, Dr. Petterssen will deliver the Fourth Wright Brothers Lecture, on the subject of "Recent Fog Investigations," at 8:30 p.m. in the Pupin Physics Laboratories building of Columbia University.

Discussers will include H. G. Houghton, Asst. Professor of Meteorology, Massachusetts Institute of Technology; Comdr. F. W. Reichelderfer, Chief, U.S. Weather Bureau; Dr. C.-G. Rossby, Asst. Chief for Scientific Services, U.S. Weather Bureau, and A. F. Spilhaus, Assoc. Prof. of Meterology, New York University.

In further observance of the 37th anniversary of the first powered flight by Wilbur and Orville Wright, arrangements have been made for the simultaneous presentation of the Wright Brothers Lecture before Branches and Sections of the Institute on December 17th. Copies of Dr. Petterssen's paper, illustrated with projection slides, will be sent in advance to all Branches and Sections so that it may be read and discussed at their meetings on the same evening that it is being presented in New York.

Frank W. Caldwell Elected to Council

At the meeting of the Council of the Institute on October 3, 1940, Frank W. Caldwell, Director of Research of the United Aircraft Corporation, was elected to membership on the Council to fill the vacancy caused by the resignation of Eugene E. Wilson.

In submitting his resignation, Mr. Wilson, who is President of United Aircraft Corporation, explained that he would not be able to devote to the affairs of the Institute the time and attention which he felt should be given by a member of the Council. His resignation was accepted with regret and an expression of appreciation by the Council was made for his participation and interest in its work in the past.

Air Transport Association's Fellowship in Meteorology

The Air Transport Association's Fellowship in Meteorology has been awarded to Herschel R. Snodgrass, who will conduct research under the Fellowship at the University of New Mexico.

Mr. Snodgrass, formerly of Portland, Oregon, is a 27 year old graduate student of the University of New Mexico. He was selected winner of this Fellowship from seven candidates by a committee composed of Chief Meteorologists of the air lines. The candidates were required, under the terms of the Fellowship rules, to submit projects having a practical application to aerology.

Mr. Snodgrass's winning research project thus involves work which will have a practical value to industry and agriculture as well as to all phases of aviation. The Fellowship, in the amount of $500.00 each academic year, is contributed to by all airlines of the United States.

Gifts to the Institute

Capt. John M. Miller presented the library with a large collection of complete volumes of magazines.

The Smithsonian Institution added to the historical collection of pamphlets in the Aeronautical Archives by presenting many old and rare publications of the Institution dealing with aeronautics.

John R. Cautley gave several early photographs of the Wright airplane.

Horace J. Alter gave a collection of volumes of early magazines.

Personnel Opportunities

The Personnel Bureau serves individual members, as well as organizations seeking to employ aeronautical specialists. Any member or organization may have requirements listed without charge.

Wanted

The Engineering Department of a centrally located aeronautical school has several openings for instructors qualified to teach airplane design, stress analysis, aerodynamics, aircraft drafting, physics, or strength of materials. Applicants should state all related experience and subjects for which he wishes to be considered. Address reply to Box 110, Institute of the Aeronautical Sciences.

Wanted—aeronautical drafting instructor with at least three years of recent aircraft drafting experience. Address reply to Box 111, Institute of the Aeronautical Sciences.

Centrally located university has opening on staff of Aeronautics Department for instructor to teach airplane design, airplane stress analysis, and allied courses; applicants should hold the degree of Master of Science or higher, and have had some experience in these subjects. Complete information should be given regarding training, experience, and salary desired. Address reply to Box 112, Institute of the Aeronautical Sciences.

Aeronautical engineers experienced in stress analysis and aerodynamics for work with aircraft manufacturing corporation; can make attractive offers to experienced men. Complete information regarding salary and past experience should be included in reply. Address reply to Box 113, Institute of the Aeronautical Sciences.

Student Branches

University of Alabama. The first meeting of the school year was held on October 9th at which talks were given on the history of the Institute by Leon Anderson, the Student Branch Scholastic and the Student Branch Lecture Awards by Robert Gillespie, The Paul Kollsman Library by Samuel Hayden. The principal speaker of the evening was Leslie Walker who spoke on "The Purpose and Objectives of the Civilian Pilot Training Program."

University of California. On September 10th, the date of the first meeting, Mr. Fred Herman, Chief Engineer of the Douglas Aircraft Company, spoke on "Steps Taken by the Engineering Department in Creating a New Design."

Carnegie Institute of Technology. Chairman Marsh opened the meeting held on October 4th and led a discussion of general matters pertaining to the Student Branch. Mr. George Hampf spoke on the activities of the Carnegie Tech Glider Club. About 26 members and guests attended.

Casey Jones School of Aeronautics. Norman Mayer gave a review of the book *Lighter Than Air Craft* by Comdr. C. E. Rosendahl at a meeting held on October 3rd. At a later meeting, Mr. Harold F. Fisher, Head of the Engine Department, spoke on the advances made in the aircraft engine field.

University of Detroit. Officers for the school year 1940–1941 are: Prof. Peter Altman, Honorary Chairman; Jack D. Peters, Chairman; Frank Lewand, Vice-Chairman; John Ripplinger, Secretary; Philip Blenkush, Treasurer.

University of Minnesota. At the first meeting, a smoker, held on October 9th, Chairman Robert Brattvet, was spokesman. The financial statement for the previous year was read by Treasurer Douglas Cone; details of The Paul Kollsman Library were given by the Secretary, Kevin Winker. Introduced in the following order were members of the Faculty: Messrs. Ruszag, Gail, Piccard, Serebreny, Stillwell, Boehnlein, and Akerman. Refreshments were served to the 200 people attending the meeting.

Rensselaer Polytechnic Institute. Chairman Anderton opened the first meeting of the year on September 26th by giving a talk on the purposes and aims of the Institute. Following this, Robert Stark gave the Student Branch Lecture "Uses of Nickel and Nickel Alloys in the Construction of Aircraft" by J. W. Sands. Professors Fairbanks and Hemke also spoke. On October 10th, Prof. Fairbanks spoke on "Seaplanes Landed." Following this, the Pan American film "Flying to Rio" was shown.

Sections

Seattle. New officers are: B. H. Galt, Chairman; F. P. Jones, Vice-Chairman; C. E. Rutledge, Secretary; H. T. Horn, Treasurer; A. F. Kelsey, Program Committee; and R. L. Linforth, Membership Committee. At a dinner meeting on September 25th, attended by about 175 members and guests, Prof. B. T. McMinn gave a talk on polarized light and photo-elastic methods of stress analysis.

Lockheed Industrial Course Engineers Affiliated with the Institute

Seventy-nine of the engineers taking the special aeronautical course conducted by the Lockheed Aircraft Corporation and the California Institute of Technology have recently become Technical Members of the Institute of the Aeronautical Sciences. The course of study in which they are engaged was inaugurated last August by the Lockheed Corporation, in cooperation with the California Institute of Technology, to give four months of intensive aeronautical training in classroom and factory to experienced engineers from other fields. Upon completion of this course they will be prepared to enter the engineering departments of aircraft manufacturing companies.

The previous education and experience of these "students" have been in many branches of civil, mechanical, electrical and chemical engineering. Their affiliation with the Institute from the beginning of their participation in aeronautical work will be of value to them in their newly chosen profession. The Institute welcomes to membership the following from the Lockheed Industrial Course who are now enrolled as Technical Members:

Archie Anders, M.S. in M.E.; Edward William Anger, Jr., B.S.; Wilbur Walter Ayers, B.S.; Willard Andrew Ashton, B.S. in M.E.; Lilburn Swisher Barksdale, B.S. in M.E.; Francis Bates, Jr., B.A.; John Cambelton Blair, B.S. in C.E.; Tenney Elmore Blake, B.S. in C.E.; Fred Joseph Boll, B.S. in M.E.; F. W. Bowden, M.S. in E.E.; Arthur F. Carroll, B.S. in E.E.; Joseph H. Castler, B.S. in M.E.; Harold Campbell Clendenen, B.S. in E.E.; James Cope Chambers, B.S. in M.E.; Kenneth Henry Coleman, B.S. in M.E.; Donald Benjamin DeNoyer, B.S. in M.E.; John A. Dickie, M.S.; Prosper Filibertus Deprez; Jean Dentraygues, M.E.; Harry Drell, B.S. in M.E.; Lloyd Sanders Dysland, M.S.; Philip Charles Efromson, B.S. in M.E.; Alf Fridtjof Ensrud, M.S.; James Thomas Eubanks, LL.B.; Clarence Francis Ewald, B.S. in C.E.; Thomas Cockrell Farris, B.S. in M.E.; Howard Adam Felten, B.S. in M.E.; Henry Moore Fussell, 3rd, B.S.; Joseph P. Gardner, B.S. in M.E.; Morris K. Goldsmith, B.S. in C.E.; William Raymond Gordon, B.S. in M.E.; Walter F. Hagman, B.S. in C.E.; Charles Frederick Hamlin, B.S. in C.E.; Edward Joyce Hartman, M.S. in E.E.; Lewis Henry Height, Eng. of Mines; Karl Hellsen, M.S. in C.E.;

Ronald Elwood Herron, B.S. in C.E.; James Warren Hill, B.S. in E.E.; Arthur O. Hoistad, B.S. in M.E.; John G. Hoser, M.S. in M.E.; Henry Luke Hoxie, A.B.; Lloyd Willard Jedeka, M.S.; William Arthur Johnson, Jr., B.S. in M.E.; Rudolf Herman Justl, B.S. in M.E.; Jacob Kadushin, B.Ae.E.; Leslie Clyde Kantner, Jr., B.S. in C.E.; Arthur Millis Kellam, M.E.; Telfer Kitchen, B.S. in C.E.; Bennett Lewis, M.E.; Robert Compton Lewis, B.S.; Thomas Jilson Martin, B.S. in E.E.; Raymond Arthur McCreary, B.S.; John Dwight McCurdy, E.E.; William Clyde McFadden, B.S.; Richard Leo McInerney, B.S. in E.E.; Jules Medow, B.S. in M.E.; Bernard L. Messinger, B.S. in M.E.; Robert Milmoe, E.E.; Jack Leonard Montgomery, B.S. in Mining Eng.; Lowell Wallin Norin; Nels Ernest Nylin; Elmer Adolph Olson, B.S. in C.E.; Eric Arthur Peterson, B.T.C.; Paul Gilbert Peterson, B.S. in C.E.; William Granger Pitt, B.S. in G.E.; Edward Joseph Prahin, B.S. in C.E.; Stephen Francis Resan, M.S.; Paul Clark Roberts, B.S. in M.E.; Everett Wilbur Rossow, B.A.; Edward Stuart Russell, B.S. in M.E.; Walter Welsch Safford, B.S.; Oscar Schuster, A.E.; Robert Martin Seyfarth, E.E.; Roy G. R. Slawson, B.S. in E.E.; Charles Emil Tillman, B.S. in M.E.; Orvil Smith Tuttle, C.E.; B. Vinson, B.S. in C.E.; William Thomas Wagner, B.S. in M.E.; John W. Young, B.S. in C.E.

Changes in Membership

The following changes in the membership of the Institute have occurred since the publication of the previous issue of the Journal.

Elected to MEMBER Grade

Armstrong, Cecil Werner, M.S. in Eng.; M.I.Ae.S.; Asst. Prof., Mech. Engineering, Univ. of California.

Bayless, Ralph Leland, B.S. in M.E.; M.I.Ae.S.; Aero. Engineer, Consolidated Aircraft Corp.

Berdelman, Harry Arthur, B.S. in M.E.; M.I.Ae.S.; Sr. Structures Engineer, Lockheed Aircraft Corp.

Blount, Earl Ellsworth, M.I.Ae.S.; Commercial Structures Engineer, St. Louis Airplane Div., Curtiss-Wright Corp.

Coleman, Robert P., B.S.; M.I.Ae.S.; Asst. Physicist, N.A.C.A.

Da Silva, Joao Mendes, M.I.Ae.S.; Capt. and Tech. Representative in U.S., Brazilian Army Air Corps.

Galt, Byron H., M.I.Ae.S.; Asst. Project Engineer, Boeing Aircraft Co.

Gillmore, William Eugene, M.I.Ae.S.; Brig. Gen. U.S.A.C. (Ret.): Asst. to Pres., Briggs Mfg. Co.

Gordon, Samuel Arthur, B.S.; M.I.Ae.S.; Chief Test Engineer, Glenn L. Martin Co.

Inglish, Harold Clark, B.M.E.; M.I.Ae.S.; Structures Research Engineer, Vega Airplane Co.

McCarty, Lewis C., Jr., M.I.Ae.S.; Vice Pres., Engineering, Central Aircraft Mfg. Co., Div. of Intercontinent Corp., China.

Miller, Louis Crossman, B.S. in Ae.E.; M.I.Ae.S.; Supervisor of Aerodynamics, Flight Test and Weights, Brewster Aeronautical Corp.

Sanford, Carl Nichols, M.Eng.; M.I.Ae.S.; Asst. Prof., Aero. Engineering, North Carolina State College.

Vensel, Joseph Richard, B.S. in Ae.E.; M.I.Ae.S.; Test Pilot Engineer, N.A.C.A.

Elected to Technical Member Grade

(In addition to those listed above from the Lockheed Industrial Course.)

Arnold, Lee, M.S.; Vibration Engineer, Glenn L. Martin Co.

Haley, Sebron McGee, Jr., Naval Aviator; Ensign, A-V(N), U.S. Naval Reserve.

Holtan, Lester C., A.B.; Pilot, Western Air Express Corp.

Lundgren, Arthur Stanley, A.A; Liaison Engineer, Douglas Aircraft Co.

Swanson, Robert St. Clair, B.S. in Eng.; Jr. Aero. Engineer, N.A.C.A.

Transferred to Associate Fellow Grade

Charles H. Niles, Asst. to Executive Engineer, Glenn L. Martin Co.; Joseph Robert Fischel, Research Engineer, Lockheed Aircraft Corp.; Wilbur C. Nelson, Asst. Prof., Aero. Engineering, Iowa State College.

Transferred to MEMBER Grade

Edward E. Brush, Senior Design Engineer, Lockheed Aircraft Corp.; Eugene C. Frost, Group Engineer, Lockheed Aircraft Corp.; C. R. de Laubenfels, Design Research, Lockheed Aircraft Corp.; N. Nelson Leonard, Jr., Tool Designer, Douglas Aircraft Co.; Albert Murray Schwartz, Assoc. Prof., Daniel Guggenheim School of Aeronautics, Georgia School of Technology; Rudolph Soellner, Engineer in charge Power Plant Design, Stinson Aircraft Div., Aviation Mfg. Corp.; Charles Edgar Sowle, Weight Estimator, Glenn L. Martin Co.; Burdell Leonard Springer, Assoc. Aero. Engineer, Civil Aeronautics Board; Charles David Stewart, Engineer, Lockheed Aircraft Corp.; George Frederic Taylor, Chief Meteorologist, Western Air Express Corp.; Robert Alden Thompson, Asst. Prof. Mechanical Engineering, Univ. of Florida; Rudolph Lawrence Thoren, Flight Engineer, Lockheed Aircraft Corp.; Harry M. Turner, Structural Engineer, Glenn L. Martin Co.; Stanley Allen Vye, Weight Engineer, El Segundo Div., Douglas Aircraft Co.; Elmer John Weitekamp, Project Engineer, El Segundo Div., Douglas Aircraft Co.; Roland James White, Aero. Engineer, St. Louis Airplane Div., Curtiss-Wright Corp.; Albert I. Wiebe, Aero. Instructor, New York City Board of Education; Louvan Elbert Wood, Director of Upper Air Instruments, Julien P. Friez & Sons; Lawrence Newton Wylder, Service Representative, Wright Aero Ltd.; Charles Horton Zimmerman, Project Engineer, United Aircraft Corp.; Harold William Zipp, Chief Engineer, Stearman Aircraft Div., Boeing Airplane Co.

Transferred to Industrial Member Grade

Edward Fenn Andrews, Director of Engineering, E. F. Andrews' Laboratories; Albert W. Dunning, Dept. of Sales, Aviation Div., Monsanto Chemical Co.; Philip Harold Schneck, Production Planning Supervisor, Curtiss Propeller Div., Curtiss-Wright Corp.; James Hopkins Smith, Jr., Asst. to Vice-Pres., Pan American Airways Co.; Raymond Pollard Wagner, Experimental Test Dept. Office Manager, Pratt & Whitney Aircraft, United Aircraft Corp.; Donald Pastorius Wilson, Liaison Engineer, Fairchild Aviation Corp.; John Howard Yeomans, Airport Mgr., Pan American Airways System.

Necrology

John William Park

John William Park, a Technical Member of the Institute, died on August 12, 1940, in an airplane test flight accident near Los Angeles, California.

Mr. Park was born in Las Vegas, Nevada, on December 15, 1915, and was educated in public schools there. He received the degree of M.E. in Aeronautics from Stanford University in June, 1938. He was a member of Sigma Xi. Shortly after his graduation from Stanford he joined the staff of the Douglas Aircraft Company, first as a student engineer, then as stress analyst and flight test engineer. He held the latter position up to the time of his death, at the age of 24.

Aeronautical Reviews

These brief reviews of recent articles on aviation subjects are published by the Army Air Corps for the information of its officers, and are printed here each month by permission of the Chief of the Air Corps

Aerodynamics

Square Root Extractor. H. D. Green. Mechanical device described is used for extracting a root or obtaining a power of successive ordinate values of curves, and is particularly useful in calculating total volume flow in a pulsating stream from velocity, or rate of flow, records obtained from venturimeters, orifice meters or pitot-tube meters in which deflection of the record is usually proportional to the square of the flow, and with hot-wire meters and thermostromuhrs in which deflection of the record is proportional usually to the square root of the rate of flow. *Rev. Scientific Instruments*, August, 1940, pages 262–264, 3 illus.

Aircraft Design

Designing for Serviceability. J. E. Thompson, Vultee Aircraft, Inc. Factors by which serviceability is governed and which should be considered in design are discussed, including: ease of inspection of wear and/or damage; minimum adjustment points; maximum "atmospheric" clearances provided for purposes of installation, assembly, and/or operation of structure and mechanisms; simplicity of lubrication; minimum number of left- and right-hand parts; ready removability and replacement of vulnerable and/or wearing parts; elimination of stress concentrations in the structural design; ease of repair; and the need for minimum special materials and tools for servicing.

Illustrations cover: outer wing-panel design that is well adapted to repair operations; composite fuselage construction facilitating service and repair operations; use of composite steel-tube and semimonocoque fuselage with removable side panels in the Vultee trainer, providing extensive serviceability; wing-gun installation in the Vultee V-12 attack-bomber in which serviceability was a basic consideration, the guns being completely accessible for installation, sighting and loading; and a bench-assembled gunner's seat which can be completely disassembled by withdrawing two bolts. *Aero Digest*, September, 1940, pages 68, 71, 72, 116, 6 illus., 1 table.

Flutter Research and Design. J. C. K. Shipp. The importance of the many parameters influencing flutter speed is discussed as a general guide to the designers of military aircraft, and the more practical aspects of flutter research are reviewed. Discussion covers: torsional stiffness; Kussner's constant as a kind of statistical check on flutter speed; structural damping; mass balancing effects; influence of weight on flutter speed, considered merely as a density effect; wing torsional damping; tail flutter; and propeller flutter. Comment is made that on the Messerschmitt Me.109 fighter there is a single spar at 45 per cent of the chord. Flexural axis cannot be far from this position, and it may be that the designer has deliberately sacrificed torsional stiffness in the hope that the wing is naturally mass-balanced. A flexural axis at 45 per cent of the chord is foreign to British practice, 30 per cent being a normal value. Illustrations include: the relation between wing density and Kussner's constant to conform with Design Leaflet B.11 of A.P.1208; values of Kussner's constants obtained from resonance test data plotted against structural wing density; variation of flutter speed with wing density for a typical wing; and effect of mass balance on flutter speed. *Aircraft Engg.*, August, 1940, pages 247–248, 4 illus., 8 equations.

Rotary-Wing Aircraft. J. A. J. Bennett. Dynamics of an articulated rotary-wing system. The approximate method described requires the solution of fourth-degree equations for obtaining the natural vibrations of a two-bladed rotor in which drag hinges are inclined downwardly and outwardly. A more accurate method is considered in which eighth-degree equations have to be solved. An analysis of a three-bladed rotor would be extremely laborious owing to the increased number of variables, and therefore of simultaneous equations. Stability with reference to pendular oscillations is attainable in a two-bladed rotor without frictional damping of the drag hinge when tan α_1 is negative; that is, when drag hinge is inclined outward and downward. This theoretical result is confirmed in practice and whenever tan α_1 is made positive it is impossible to drive the blades up to their take-off speed owing to the uncontrolled motion of the rotor tip-path plane as predicted by theory. Concluded. *Aircraft Engg.*, August, 1940, pages 237–241, 246, 5 illus., 23 equations.

Aircraft Accessories

Anti-Friction Bearings of High Capacity. E. K. Brown, The Torrington Co. Various aircraft and engine applications of small rollers without cages, which have been extensively used by the automotive industry in transmissions and universal joints. Data concerning correct clearance and load capacity of the bearings are presented, including: a table of values for quick calculation of bearing dimensions; the formulas used to determine the required size of bearing elements; and a table taken from the Torrington catalog giving load capacities for standard bearings carried in stock.

Illustrations include: load factor to be applied to the bearing ratings to obtain the shaft capacity for shafts below the recommended hardness; approximation of the hardness necessary to take care of high speeds; a series using an X-tra capacity bearing with inner race and retaining washers securely fastened to the inner race; a bearing series giving the maximum capacity obtainable from rolls used in the bearing; maximum static non-Brinell capacity of various bearings plotted against shear strength of standard AN bolts; special landing-gear bearings designed for maximum capacity; thin-shell needle bearing applied to the rocker arm of an inline aircraft engine; and applications of needle bearings to cowl ventilator flaps, to a variable-pitch propeller mechanism, to a power-operated gearbox, to a hand-control unit assembly for an engine-control stand, to the hydraulic actuating cylinder of a landing-gear mechanism (used because of the high static-load capacity of the needle bearing), to rudder pedals, and to Lockheed rudder-pedal torque-tube assembly. *Aero Digest*, September, 1940, pages 88, 91–92, 95, 108, 17 illus., 2 tables.

Tricycles Again. "Weight and expense" of the tricycle alighting gear "will be amply justified if only in the savings of unnecessary minor and major tragedies at the end of bombing raids . . . . aeroplanes must be designed round the tricycle . . . . the entire machine must be thought about all over again . . . . Not only must the general design be reconsidered from the word 'go,' but such items as flaps and brakes must be specialized. If necessary, the tricycle must await the further work of designers on such items." Comments on flying full-size airplanes with tricycle landing gear, and referring to effect of short wheelbase, need for redesign of flaps, and undercarriage loads. *Flight*, August 15, 1940, pages 124a–124b, 1 illus.

Aircraft Maintenance

Mainliner Maintenance. Methods employed by United Airlines in the maintenance of Mainliner airplanes and their engines, propellers, and equipment at the overhaul shop at Cheyenne are described. Each Douglas is routed there after 600 hr. flying time, and engines are completely disassembled. Special shops, which tend to make United's base unique are furnished with a variety of special equipment which exists at no other airline base. Shops are divided up into the engine, propeller, accessories, instrument, radio and electrical, sheetmetal, machine and battery shops. In each of these shops are specialists in that particular kind of work, as well as super specialists who concentrate on one phase of the work. *Aviation*, September, 1940, pages 32–33, 116, 122, 126, 7 illus.

Aircraft Manufacture

Aircraft Machine Tools at the Northrop Plant. R. R. Nolan. Machine tools installed in Northrop Aircraft's plant at Hawthorne, Calif., are described briefly with references to some of the operations performed on them. Machines include: Van Norman universal milling machines; Do-All Continental saw for contour sawing; Jones and Lamson turret lathes for long-run turning jobs; American radial drills; Standard Cincinnati gap shears of 12-ft. and 6-ft. capacities and equipped with special gages and stops; Northill shears, designed for aircraft production work; Steelweld power brakes; and the Onsrud "router" for high-speed milling of several thicknesses of aluminum-alloy contoured sheets and designed exclusively for aircraft production. The Northrop furnace for heat treating aluminum alloys is described in more detail. It is said that special machines, principally of Northrop design (compression riveters, gang punches, high-speed trimming machines, extrusion benders, and special rolls) are also used but no mention is made of their names or applications. *Aero Digest*, September, 1940, pages 84, 87, 184, 10 illus.

Aircraft Riveting. H. S. Broom. Various types of machines and different methods available, including percussive and compression or squeeze riveting and riveting by special mechanical means, are described. Some points requiring attention for successful results are considered. Mounting of yokes, pop hollow rivets and the Chobert hollow rivets are also discussed and illustrated, and the mechanism of the Chobert riveting gun is shown in a drawing. *Aircraft Production*, August, 1940, pages 256–260, 19 illus.

Italian Assembly in Wood and Metal. Final assembly operations on the Fiat B.R.20 are shown in three photographs giving an idea of the procedure in use and illustrating the composite metal and fabric construction. Four other photographs indicate the stages in assembly of the Caproni Ca.310. While the main plane is made in one piece and the engines assembled to ft in the final operation, the three sections of the fuselage are not joined until the final assembly to the main plane. Photographs only. *Aircraft Engg.*, August, 1940, page 255, 7 illus.

Junkers Stretching-Press Technique. In Germany not only are fuselage coverings shaped on the press but also whole engine covers, wing-tip formers, end caps for wing and tail units, N.A.C.A. cowlings, slot covers, wing-root fairings, exhaust manifolds, and sections for fuselage, wings, engine and undercarriage. Metal is stretched without use of a holder or draw ring and tools are simple wooden patterns. Table containing the pattern is raised hydraulically. Advantages of the stretch-pressing method over that of drawing in forming light metals are discussed, and the presses and stretch-pressing technique used are described. Recommendations are made regarding: removal of folds; correct use of the pattern on which success of the pressing operation depends; manufacture of patterns and their materials; and lubrication of metal and pattern. Translated from "Junkers-Nachrichten." *Aircraft Engg.*, August, 1940, pages 251–252, 254, 7 illus.

Men and Machines. Gleason Revacycle mass-production machine for cutting straight and bevel gears. American Broach 4 HC-18 broaching machine equipped for finish broaching the half-round slots in differential cases. Millholland No. 4 ram-type universal turret lathe. Hanna electric-hydraulic riveting press available in capacities of 10 to 100 tons. National Broach Red Ring machine for precision grinding of master gears and involute broaches. Unit Machinery Polymatic high-speed screw machine for cutting small-size stock. Descriptions of these machines and references to other new items of equipment. *Automotive Industries*, September 1, 1940, pages 208–211, 234, 9 illus.

Modern Machine Tools. Walker Model D-B surface grinder for grinding concave surfaces. Ex-Cell-O hydraulic power unit which can be adapted for building special-purpose equipment. F.B.2 Precimax machine arranged for boring gudgeon-pin holes in aircraft-engine pistons. Daniel Smith section rolling machine. Farnham rolling machine especially developed for production of leading-edge skins of aircraft wings and tailplanes. Descriptions of this British equipment. *Aircraft Production*, August, 1940, pages 261–263, 8 illus.

Modern Machines for Improving Production. H. F. Schwedes. In order to be able to make the necessary parts of a modern airplane on a production basis, North American Aviation has built up a modern and extensive aircraft machine shop which makes all small jigs and fixtures, parts for experimental ships, machined parts for wind-tunnel models, and does all machine work for maintenance, as well as making the 25,000 to 30,000 parts required each week for production. New machine tools which the machine shop has

acquired in the past several months, and some of the work given to them are described. Machines include the Keller toolroom machine, Blanchard surface grinder with latest type of Neutrol demagnetizing unit, Cleereman jig borer, Van Norman milling machines, and the small Ex-Cell-O boring machine. *Aero Digest*, September, 1940, pages 56, 59, 184, 10 illus.

New Equipment. New fully-automatic X-ray machine that will photograph 5000 average parts a day installed at the Lockheed factory by Tripplett and Barton Laboratories. Three new Thor electric bench grinders. New developments in the line of Porto-Power hydraulic equipment recently developed by Blackhawk Manufacturing Company for pushing, pulling, clamping, pressing, bending and spreading operations. Farrell-Birmingham 2200-ton-capacity hydraulic press for blanking and forming duralumin aircraft parts. Method for melting zinc used in dies, developed at the Glenn L. Martin Company, and equipment employed. Spencer stereoscopic microscopes useful in the examination of small objects and precision parts in the aircraft factory. Portable Liftable placed on the market by The Service Caster and Truck Company, and serving as a work bench, floor truck and lifter. Lake Erie 150-ton hydraulic press having unusually long stroke and specially designed for drawing cartridge cases, but also applicable to other work. Harris Model "K" portable motor-driven gas-cutting machine for cutting steel of light or heavy section. Reeves variable-speed control units which are finding use in the aircraft manufacture, particularly in connection with testing apparatus. New J-B tap grinder developed by Edward Blake Company and used for sharpening or chamfer grinding of taps. Black and Decker's high-speed portable tappers, the Holgun, Tapgun and Scrugun. Hermance process devised to detect the smallest flaw in metal and other substances used in making aircraft and engines, and consisting of placing part to be tested between a sheet of color photo paper on one side and piece of platinum or other inert metal on the other. H. & H. versatile tool for production work having a powerful reciprocating action. Scotch cellulose edging tape for edging blueprints and drawings, produced by the Minnesota Mining and Manufacturing Company. *Aero Digest*, September, 1940, pages 163–164, 167, 171–172, 11 illus.

Plastic Aircraft. Construction of aircraft wings and fuselage of spruce plywood impregnated with phenol-formaldehyde is considered. Methods used by Timm Aircraft Corporation in the production of a two-seater monoplane are discussed, including materials used, plywood construction, component assembly, final stages, and advantages of the construction in regard to service repairs. Under an acetylene flame the wood could not be burned and weight was found to be 20 per cent less than the weight of the orthodox metal construction would have been. It is now proposed to proceed with the construction of a large and more powerful type of aircraft powered with a 1000-hp. engine and based upon experience gained with the prototype. *Aircraft Production*, August, 1940, pages 243–244, 7 illus.

Production by Drop Hammer. A new technique, which has been evolved by F. Riches for the awkward process of double curvatures, promises to be very successful. Swagings are used to trap the edges of the material and so to give a true draw in the center. Method also has the advantage that the swaging around the edge holds the sheet securely to prevent its buckling before delivery. General Aircraft, Ltd., were pioneers of the technique, built the first drop hammer to be used on aircraft work in Great Britain, and now have the biggest drop-hammer shop in the country. Advantages and applications of the method are pointed out, and technique used at the General Aircraft plant is described. *Aeroplane*, August 16, 1940, pages 180–182, 7 illus.

Spot and Seam Welding of Light Metals. C. Haase. Recommended German practice in spot and seam welding of aluminum and magnesium alloys is discussed, including: effects of welding current, time, tip load, and spot spacing on static strength; effect of heat treatment after welding; results of pulsating tension fatigue tests on a number of types of welds in a modified D.V.L. machine; and types of fracture. Tables give data on: effect of current and time on double rows of spot welds in duralumin 0.039 in. thick; effect of heat treatment after welding on duralumin spot welds; effects of self-heat treatment on high-strength seam welds in duralumin 0.039 in. thick; fatigue strength of single spot welds; and pulsating tension fatigue strength of different spot-welded joints in Al-7 per cent Mg alloy 0.079 in. thick.

Illustrations include: static breaking loads and diameters of single spot welds in sheets 0.039 in. thick as a function of current and as a function of time; slug obtained in Al alloys welded in 1 cycle; effect of tip load on static breaking load and diameter; effect of spot spacing on breaking load per spot, and on strength of seam for Alclad duralumin and Al-7 per cent Mg alloy for single-row spot welds; and effect of tip load on breaking load per spot for single-row closely-spaced spots (0.47-in. spacing) in Alclad duralumin 0.039 in. thick. Translated from V.D.I., February 10. *Welding Jour., Welding Res. Sup.*, August, 1940, pages 307s–310s, 7 illus., 5 tables.

Stack Cutting Aircraft Parts. Economical method of using the torch for profiling sheet steel is described, including: hand or automatic operation; light gage metal that must be used; cleaning the sheets; clamping methods (U-clamps and pneumatic clamps); adherence of sheets; cutting procedure; small parts; and saving in labor costs. *Aircraft Production*, August, 1940, pages 253–255, 5 illus.

Tools of Laminated Wood. Advantages of laminated wood over metal dies in the small-quantity production of light-alloy pressings are described. Jabroc is suited to the manufacture of forming dies and other tooling equipment. Made from selected Canadian birch veneers impregnated by means of an alcoholic solution with phenol-formaldehyde and subjected to great pressure while hot, it possesses extremely high strength in compression of the order of 40,000 lb./sq. in. Typical applications illustrated include: a trimming block used to clean up the edges and the weld of a large fairing; press forming tools for producing external flanges and stiffening ribs, and for raising flanges of the lightening holes; and routing templates and forming tools for a trailing edge rib, one also acting as a drilling jig for the various attachment rivet holes. *Aircraft Production*, August, 1940, pages 264–265, 4 illus.

Track Assembly. F. G. Miles. "We of Phillips and Powis believe that we are the first really to establish a mechanically-moved track assembly line system for the quantity production of air-craft."

In the case of the final erection of the Miles Master, a track, similar to a tramway line, is laid flush with the floor, and small carriages, on to which the airplane wheels are fastened, run on the rails. Carriages are coupled together so that the aircraft are evenly spaced down the shop. When a stage is finished, an electric warning system provides the necessary indication and an electrically-driven winch pulls the whole line down the shop into the next stage in a few minutes.

Difficulties of designing military aircraft for flow production are pointed out, advantages and initiation of the track assembly are discussed, and its operation described. A new type of discipline has to be enforced and all sorts of things that used to be hidden encouraged into the open. Waiting time is no longer a sign of a foreman's inefficiency; it is a signal for the progress department to pick up and remedy the shortage troubles at once. The system of discipline is described. *Flight*, August 22, 1940, pages 146–149, 5 illus.

Similar description. *Aeroplane*, August, 23, 1940, pages 200–203, 9 illus.

Work Simplification Increases Output. Work simplification program was planned just over a year ago in the Glenn L. Martin plant, already rated high in straight-line aircraft production, and in September, 1939 the system began to function. Many time-saving devices and many examples of improved efficiency resulted, even involving such simple process as the inspection of a bolt. The program and some of these innovations to increase output are described. *Aero Digest*, September, 1940, pages 55, 184, 2 illus.

Aircraft Performance Testing

Flight Test Inspection Procedure. N. J. Clark, Lockheed Aircraft Corp. Three phases of the airplane's progress are of immediate concern to the flight inspector of an aircraft company—pre-flight inspection, test flight, and post-flight adjustment and inspection. Where a number of similar aircraft are to be built and subsequently test-flown, the flight inspector, after studying the requirements, should make up a check list, including each item that requires attention, and grouping items so that they may be checked in logical order and in minimum time. The sequence of inspection prepared for a typical twin-engine transport airplane is described in great detail. *Aero Digest*, September, 1940, pages 60, 63, 116, 6 illus.

Testing Apparatus

Flight Test Data Mechanically Recorded. J. B. Darragh, Jr. Planetest Magnograph described is used at Lockheed Aircraft Corporation during aircraft flight test work and is a portable device which the pilot holds in his lap while he is making his flight observations. During the flight test, the pilot says aloud that he is flying at a certain altitude, that his speed is at that moment so many miles per hour, that the tachometer reads so many r.p.m., and what the pressure instruments and hydraulic gages register. He talks away at a rate of some 200 words/min., covering the necessary details of a flight test, without writing down a note in a logbook or check chart. Where more than one man is employed in the flight test, the procedure basically is the same, except that each man has a magnograph and its accessory gadgets.

Limitations of the recording oscillograph and advantages of the wax and film recorders over it are discussed. The plane-test recorder is described by means of which noise measurements can be made in a minimum of flying time. The steel-tape recorder is especially adaptable to recording vibrations and flutter measurements because the record obtained is in the form of a voltage, and can be analyzed electrically. Recording instrument readings, the testing of small airplanes, such as single-seater pursuit and interceptor types, and reproducing methods available are also discussed. *Aero Digest*, September, 1940, pages 96, 99, 180, 4 illus.

Aircraft

Germany

Arado AR-96B—Germany's Standard Military Trainer. AR-96B two-place tandem low-wing transitional trainer of all-metal construction is intended to take the student through the elementary to the advanced stage where he is ready to step into the fighting airplane. The trainer can also be used for training pilots and observers in machine gunning and bomb dropping, for training observers in aerial photography, and for actual military work in short reconnaissance, light fighting, and policing. Its full-monocoque fuselage employs a series of transverse rings and extruded and smooth longitudinal stringers. Armament includes a fixed machine gun for the pilot, having 500 rounds of ammunition and firing through the propeller disk, and a movable machine gun with 375 rounds of ammunition. Two racks, each for three 22-lb. bombs, are located on each side of the wing for bomb dropping. A Zeiss panoramic mapping camera or a hand camera is used for training in photography.

Wing span 36 ft. Wing loading 20.8 lb./sq. ft. Maximum speed 211 m.p.h. Landing speed 63 m.p.h. Rate of climb 1300 ft./min. Service ceiling 23,300 ft. Cruising range 670 miles. Argus As410A 12-cylinder vee air-cooled engine rated at 450 hp. for take-off, and 360 hp. at 3100 r.p.m. at 9840 ft.

Aero Digest, September, 1940, pages 111–112, 10 illus.

The Messerschmitt Bomber. New Jaguar bomber bears a strong likeness to the Me.110 fighter but the transparent nose gun position is different and resembles that of the Heinkel He.111K. The Jaguar carries a crew of four and armament includes several light and heavy machine guns. It is powered by two liquid-cooled engines, probably D.B.601s. Few details only, an artist's drawing of the bomber, and photograph of the gunner at his station in the nose. *Flight*, August, 15, 1940, page 124c, 2 illus.

Italy

A Multi-Purpose Italian. A recent and very versatile type of Caproni is known under at least three different guises, the Ca.311, the Ca.312 I.S., and the Ca.312 bis, each being powered by two Piaggio P.XVI 650-hp. engines. Airframe is identical in all three types and is of mixed construction. The Ca.311 landplane is intended for reconnaissance and light bombing. The Ca.312 I.S. floatplane carries a torpedo in a streamline housing under the fuselage, and the Ca.312 bis is identical in every respect with it but instead of the torpedo it carries two bombs stowed internally in the fuselage. Defensive armament in both seaplane versions comprises two machine guns, one in the port wing and the other in a turret on the top of the fuselage to cover the whole upper hemisphere. Entire front portion of the fuselage is covered with a transparent material over a framework of steel angles and tees, and nose portion can be opened to give the bomb aimer a chance to escape. Airplane is the same size as the Blenheim, but is equipped with lower powered engines and therefore cannot be as fast as claimed, particularly when fitted with floats.

Wing span 53 ft. 3 in. Wing loading about 30 lb./sq. ft. *Bomber:* tare weight 8800 lb.; disposable load 3520 lb.; claimed maximum speed 249 m.p.h. at 13,100 ft.; climb to 13,100 ft. in 13 min.; range with full military load 560 miles; ceiling 19,700 ft. *Torpedo plane:* disposable load 3740 lb., claimed maximum speed 236 m.p.h.; climb to 13,100 ft. in 16 min.; range with full military load 373 miles; ceiling 16,400 ft. As used for reconnaissance, range 1000 miles. Description. *Flight*, August 22, 1940, pages 144a–144b, 5 illus.

Some Italian Military Types. Appearance and construction of the more recent machines used in the various branches of the Italian military service are described in detail, and principal characteristics are given for the following: *Bombers.*—Savoia Marchetti S.M.79 (three Alfa Romeo 126R.C.34 engines); Fiat B.R.20 (two Fiat A80 R.C.41 engines); Caproni Ca.135 (two Piaggio P.XI R.C.40 engines); and Piaggio P.32 bis (two Piaggio P.XI R.C.40 engines).

Attack Bombers.—Breda 88 (two Piaggio P.XI R.C.40, speed 344 m.p.h.), and Breda 65 (Fiat A.80 R.C.41 or Piaggio P.XI R.C.40 engines, maximum speed at 16,400 ft. 267 m.p.h. and 254 m.p.h.).

Fighters.—Fiat C.R.32 ter (Fiat A.30 R.A. bis engine, maximum speed at 9840 ft. 230 m.p.h.); Fiat C.R.42 (Fiat A.74 R.C. 38 engine, maximum speed at 13,100 ft. 280 m.p.h.); Fiat G.50 (Fiat A.74 R.C. 38 engine, maximum speed at 12,500 ft. 304 m.p.h.); Macchi C.200 (Fiat A.74 R.C. 38 engine, maximum speed at 15,700 ft. 314 m.p.h.); and Caproni Vizzola F.5 (Fiat A.74 R.C. 38 engine, maximum speed not disclosed).

General-Purpose Types.—Caproni Ca.310 (two Piaggio P.VII C.35 engines, maximum speed at 13,100 ft. 230 m.p.h.); I.M.A.M. Ro.37 (Piaggio P.IX R.C.40 or P.XR. engine, maximum speed at 18,200 ft. 205 m.p.h. and at 6560 ft. 198 m.p.h.).

Seaplanes.—Cant Z.506-B (three Alfa Romeo 126R.C. 34 engines, maximum speed at 13,100 ft. 236 m.p.h.); Macchi C.99 (two Isotta-Fraschini Asso XI R.C.15 engines, cruising speed 168 m.p.h.); Cant Z. 501 (Isotta-Fraschini Asso XI R.2 C.15 engines, maximum speed at 8200 ft. 171 m.p.h.); I.M.A.M. Ro.43 and Ro.44 (Piaggio P.X.R. engine, maximum speed at 8200 ft. 186 m.p.h. and 190 m.p.h., respectively); and Caproni Ca.312 I.S. and Ca.312 bis (two Piaggio P.XVI engines, maximum speeds at 13,100 ft. 236 and 248 m.p.h., respectively). *Aircraft Engg.*, August, 1940, pages 224–232 and 246, 27 illus., 5 tables.

U.S.A.

Aviation Sketch Book of Design Detail. Drawings and brief descriptions of the following: structure of the Luscombe Model 8A; new exhaust system of the new Aeronca Models 50-TL and 65-TL; metal and wooden engine mount of the Johansen JA-2 and the brackets suspending the engine from the semimonocoque wood construction; pilot's seat designed and built by the Kellett Autogiro Corporation of 24-ST Alclad construction spot welding, and adjustments possible; and fixed wing-gun installation of the Martin 167F Reconnaissance Bomber consisting of two 0.30-caliber machine guns, cartridge boxes and firing solenoids. *Aviation*, September, 1940, pages 62–63, 6 illus.

Consolidated Bomber XB-24. Latest four-engine long-range bomber of the U.S. Army Air Corps has a wing incorporating the new Davis airfoil which is a thinner section than generally used. Makers claim a speed of over 300 m.p.h., a range of 3000 miles, and a bomb-carrying capacity of 4 tons. Gross weight is 40,000 lb. and wing span 110 ft. Crew varies from 6 to 9 persons depending on the mission. The XB-24 is briefly described, and an abstract of U.S. patent No. 1,942,688 for the Davis airfoil is given, including formulas for laying out the two profile lines so that they have a definite relationship for each given type of airfoil. Equation is said to have been developed from formulas based on the mechanical action of a rotor having rotation and translation through a fluid. *Flight*, August 22, 1940, pages 145 and 152, 1 illus.

The Culver Cadet. The Model L-CA two-place low-wing monoplane for the private pilot has retractable landing gear enabling the airplane to reach a top speed of 140 m.p.h., and a slotted wing providing better lateral control and increased ease of landing. Continental 75-hp. engine. Wing span 26 ft. 11 in. Wing loading 10.88 lb./sq. ft. Cruising speed 120 m.p.h. Stalling speed 45 m.p.h. Rate of climb 800 ft./min. Service ceiling 17,500 ft. Cruising range 600 miles. *Aviation*, September, 1940, pages 55, 131, 5 illus.

Grumman "Widgeon" 4 to 5 Place Amphibian. Model G-44 Widgeon is a scaled-down version of the G-21 amphibian except for minor changes, and has a useful load of 1450 lb. It is designed so that it is easy to fly and simple to maintain. Power is supplied by two 200-hp. Ranger inline engines, each fed by individual fuel lines supplemented by a crossflow system which is the only line in the cabin. Wing span 40 ft. Cruising speed 150 m.p.h. Cruising range 680 miles. *Aero Digest*, September, 1940, pages 107–108, 3 illus., 1 table.

Short description. *Aviation*, September, 1940, page 49, 1 illus.

New All-Metal Light Plane. Performance figures obtained in tests of the new Naugle all-metal light plane include a top speed of approximately 130 m.p.h. with a Lycoming 75-hp. engine, a landing speed of from 40 to 42 m.p.h., without flaps, and a climb of 1000 ft./min. Experiments are being carried out on the use of flaps which are expected to reduce the landing speed greatly. Retractable landing gear is being designed and from the test data so far available the top speed of the plane is expected to be about 150 m.p.h. and the landing speed to be about 40 m.p.h. Few details only. *Aviation*, September, 1940, page 49, 1 illus.

Pitcairn Model PA-36 Direct Control Autogiro. D. Rose. PA-36 autogiro which is described in detail is a "direct control," wingless craft in which all longitudinal and lateral control is accomplished by tilting of the rotor hub. Hub is of the modified "centralized" type, in which axes of flapping hinges are moved close to the center of rotation, the plane of rotation of blades being practically coincident with the plane of control motions. Incorporated in the hub also is a two-position pitch-change mechanism which permits the blades to be set at their no-lift pitch angle while the rotor starter gives them flying r.p.m. approximately 50 per cent above normal. When the blades are set at their normal operating pitch, a direct take-off of approximately 15 ft. will be accomplished, rendering the machine largely independent of ground obstacles.

The Warner engine, rated 175 hp. at 2250 r.p.m., is cooled by a blower which takes air in through a duct at the front of the fuselage, and distributes it over the cylinder heads and barrels. No other performance or characteristic figures are given. *Aero Digest*, September, 1940, pages 104, 115, 2 illus.

The Pitcairn Whirl Wing. A. E. Larsen. The Whirl Wing, new "jump" autogiro, is capable of a vertical ascent from the ground of from 15 to 35 ft., depending on wind conditions. Description of the autogiro includes: advantages gained by enclosing the engine within the fuselage; use of a driveshaft from engine to transmission; installation of a flywheel to remove any tendency toward torsional vibration in the shaft, and of an integral Sirroco fan around the flywheel perimeter for forcing the air through the cooling system; ring gear making possible the use of a standard automotive-type electric starter; principles on which the jump take-off operates; and general arrangement of the power and control units within the Whirl Wing. Warner Super-Scarab 175-hp. engine is separated from the cabin by an insulated metal bulkhead. *Aviation*, September, 1940, pages 46–47, 131, 6 illus.

Air Transportation

Airline Research. J. P. AuWerter. Research organization, activities, and laboratories of United Airlines are described in detail, including research and development of new radio equipment, engineering research, and flight medical research. Each of the various research departments has its own facilities, and there is also equipment available to all three. Foremost are the flight-research airplane, a converted Boeing 247-D transport, and the altitude chamber for testing equipment in which actual flight conditions at altitudes varying from sea level to 65,000 ft. may be simulated. *Aviation*, September, 1940, pages 30–31, 106, 110, 114, 13 illus.

20th Anniversary of the Coast-to-Coast Airway. Development of the cost-to-coast air-mail and passenger air-transport service is described. *Aero Digest*, September, 1940, pages 64, 67, 115, 9 illus.

Trans-Atlantic Again. First direct crossing of the Atlantic in 1940 by a British commercial airplane was made by the flying boat "Clare" recently. Account of the round trip. *Flight*, August 15, 1940, pages 132–133, 5 illus. *Aeroplane*, August 16, 1940, page 167, 2 illus.

Founding the Air Lines. Development of British commercial air-transport lines since its beginning 21 years ago is traced with photographs of the aircraft used during this period. *Aeroplane*, August 23, 1940, pages 204–205, 12 illus.

Propellers

The Bases of V.P. Airscrew Design. K. A. Schmidt. A stageless governor giving any desired propeller revolutions, and an infinite range of adjustment are fundamental requirements of variable-pitch propeller design, and these are provided by all three German types. The V.D.M., Junkers and Argus variable-pitch propellers are described with cutaway drawings showing, in particular, the pitch-changing mechanism of the Junkers and Argus propellers. References are made to Hamilton, Curtiss, Rotol and other propellers.

Fundamental requirements for variable-pitch propellers to which airplane development has led in recent years are considered in great detail, particularly conditions for diving and take-off. Several German basic solutions for the support of the extraordinarily high centrifugal forces on the blades and for the otherwise rather scanty operational conditions with such bearings are described including the bearings developed by the Schwarz Company. Basic operational process of the governor is sketched. Problems of the quantity of energy required to satisfy the various conditions for varying the pitch, and of conducting it efficiently in its most appropriate form to the propeller blades are taken up.

In the Argus propeller, pitch adjustment is effected by means of a ribbed nose cover capable of rotation relative to the main hub cover and connected with the adjusting mechanism through the governor in a pitch decreasing or increasing sense. Moment required for making the adjustment, and transmitted through the mechanism to the blades, is provided by the air resistance offered to the ribbed cover in this condition of rotation. Pitch adjustment of the V.D.M. propeller is made by means of an electric motor of 80-120 watts through a set of planetary pinions. Junkers variable-pitch propeller is fully-automatic. By means of an oil pump operated by the engine, the required volume of oil is delivered to an oil-operated motor, between two oil-tight joints in the hub. Gearing required permits blade-setting over the entire angular range of 360°. Translated from "Luftwissen," October, 1939. *Aircraft Engg.*, August, 1940, pages 233–236, 11 illus.

Curtiss Propeller Production. The present 1900 employees now use a total of 220,000 sq.ft. in the Curtiss Propeller plants. About 1300 of these men are engaged in actual manufacturing processes, while the new plant at Caldwell, N.J., will make room for 1600 more employees. Operation of the plant, preliminary work done before the propeller is actually scheduled for production, the engineering and manufacturing departments, and processes on the aluminum-alloy and hollow steel blades and on the hub are described. To be continued. *Aviation*, September, 1940, pages 40–43, 15 illus.

Variable-Pitch Airscrews (V.P. and Constant-Speed Control). H. N. Charles. Functions of a modern fully-controllable variable-pitch propeller are discussed, including: acting as a fixed-pitch propeller for testing the engine on the ground; "constant speeding" during take-off and climb, and all maneuvers during aerobatic flight; locking the pitch in any position in the air; making it possible to control the pitch manually, quite apart from the constant-speed governor; feathering the propeller when it is desired to stop its rotation during flight; unfeathering the propeller gently or suddenly according to requirements; and reversing the propeller to assist non-flying maneuvrability, particularly in the case of large multi-engined flying boats on the water. At least one all-British make of propeller possesses all of these attributes. A sectional view of the new Rotol electrically-operated variable-pitch propeller is illustrated. *Flight*, August 15, 1940, pages 124d–124f, 3 illus.

Equipment

New Equipment. Jadur flight calculator for providing essential information to the pilot in flight, or when he is preparing his flight plan. New engine-driven gear-type hydraulic pump developed by the Pump Engineering Service Corporation, for operation of wing flaps, landing gear and other high-pressure hydraulic units in aircraft. Bowser Serv-A-Plane refueling unit for use at airports. New gasoline engine heater developed by Otto Bernz Company, and incorporating many improvements. Specialized Goodrich compounds of natural rubber and synthetic rubber with a high degree of electrical conductivity. New flight-level indicator developed by the Civil Aeronautics Board. LeTourneau method of hangar construction said to possess structural rigidity, simplicity, and economy. Pistol-grip carbon-dioxide fire extinguisher made by Walter Kidde and Company. Boardman two-compartment airport refueling truck manufactured for Braniff Airways, and having a 1400-gal. tank made of Armco steel and a fuel pump capable of delivering 120 gal./min. New Timken tapered roller bearing, adapted to serve as a sheave bearing. Adel four-way hydraulic selector valve with provision for either automatic or manual return from operating to neutral position, thus relieving the pilot of an operation and saving time in the manipulation of hydraulic controls actuating the landing gear and flaps. Short descriptions. *Aero Digest*, September, 1940, pages 163, 167–168, 171–172, 6 illus.

Buyers Log Book. Few details only of what's new in airplane accessories, materials, supplies, and equipment. *Aviation*, September, 1940, pages 66–67, 9 illus.

Fuels and Lubricants

Synthetic Fuels for Aviation. J. P. Eames. Recently, the Standard Oil Company of California installed a huge synthetic-fuel blending plant, or hydrogenation plant, in its refinery at Richmond, Calif. Steps composing the process underlying the production of this latest development in aviation fuel, and the hazard involved in the actual production of hydrogenated aviation fuel blends are discussed. *Aero Digest*, September, 1940, page 75, 1 illus.

Metals

Fatigue Failure. G. Sachs. The close relation between the three types of stress raisers is not generally recognized as yet, and in any one of the three special types of fatigue discussed little benefit is derived from alloying and heat treatment.

First issue—Effects of machined notches and corrosion simultaneous with fatigue on the fatigue strength of metals and alloys are considered.

Second issue—Chafing fatigue and the effects of surface working on the fatigue strength in the presence of stress raisers are discussed.

Extent of the strength reduction by chafing increases with the pressure which is exerted by the press fit, or bearing on the gripped surface. Surface films of a metallic or nonmetallic nature have no beneficial effect on chafing

fatigue strength, while they reduce the wear and formation of the oxidized powder at the area of contact. A thick intermediate layer of a yielding fabric has been found to produce an increase of chafing-fatigue strength. Factor or factors associated with localized surface deformations which cause the improvement of the fatigue properties is not yet quite apparent. There may be a certain improvement in the properties of the surface layers by the cold deformation. A more convincing theory considers the main factor to be an accumulation of high compression stresses in the surface layers which render the metal more resistant to the effects of stress raisers on fatigue.

Drawings and curves show: relation between chafing fatigue strength and regular fatigue strength for various aluminum alloys and for annealed and cold-worked duralumin; stress-cycle diagrams of normalized cast and wrought mild steels in regular and in chafing fatigue; effect of grip pressure on the fatigue strength of cylindrical cantilever type specimens; effect of various stress raisers of the chafing and corrosion types and effect of surface rolling on fatigue characteristics of a magnesium propeller alloy; device for surface rolling; effects of surface rolling with different pressures and of an intermediate fabric layer on fatigue strength of 2 3/4 in. diameter magnesium-alloy rods; and residual stresses developed in a magnesium alloy rod by surface rolling. Correlated abstract. *Iron Age*, September 5 and 12, 1940, pages 31–34 and 36–40, 15 illus.

Modern Assembly Processes. J. L. Miller. First issue—Hard soldering and brazing. Employment of silver solders in engineering practice and advantages to be gained by their adoption are considered. Arrangements for silver soldering in a spot welder and in a seam welder are shown in drawings. Factors governing the choice of brazing alloys are outlined. Methods available for heating, such as electric-resistance, carbon-resistance and furnace heating, and fluxes are also dealt with. Melting points of copper-silver alloys and brasses are given in a table.

Second issue—Hydrogen furnace brazing. Importance of capillary attraction in copper brazing is pointed out. Permissible limits in the fit of brazed parts and methods of obtaining well fitting joints are described. Illustrations include: brazing tungsten to contact rivets; grain growth across a joint caused by excessively tight fit; correcting a slack fit by punching; tightening a crankpin in position; head roller riveted, then brazed; and methods of brazing a tube to a plate. Continued. *Metal Industry*, August 9 and 23, 1940, pages 109–111 and 147–150, 16 illus.

NONFERROUS ALLOYS

Machining of Aluminium Alloys. W. A. Dean. General survey of modern American practice, and classification of more than 40 commercial aluminum casting and forging alloys. First issue—General machining characteristics of each group are described and some general rules laid down for machining them. Second issue—Individual machining operations such as turning and milling and tool design are considered. *Metal Industry*, August 9, 1940, pages 102–105, 1 table.

WELDING AND FLAME HARDENING

Applications for Pulsation Welding Broadens the Field of Resistance Welding. H. C. Cogan and R. S. Palton. Machine used in the production of torque tubes for automobiles is illustrated and described, and advantages of pulsation welding are outlined. Welding techniques for pulsation spot welds and pulsation projection welding are shown in tables. The pulsation spot welding of large frame assemblies by means of portable resistance welders is described. *Welding Jour.*, August, 1940, pages 568–571, 3 illus., 2 tables.

Jigs and Fixtures for Oxyacetylene Welding. J. Haydock. Basic requirements of a well-designed welding jig are explained, and the application of these principles as they are worked out in practice is discussed. *Welding Jour.*, August, 1940, pages 549–552, 10 illus.

Welding Magnesium and Its Alloys—Review of Literature to July 1, 1939. W. Spraragen and G. E. Claussen. Oxyacetylene, spot, seam, flash, resistance-butt welding and other resistance welding methods for magnesium and its alloys, soldering, and fire hazards are considered. Oxyacetylene welding is discussed in regard to field of application, preparation of the joint, flux, filler rod, flame, welding procedure, finishing the weld, structure, cracks, mechanical properties, corrosion, and castings. Spot welding applications and procedure, corrosion, and mechanical properties are taken up. Research problems are suggested. *Welding Jour.*, Welding, Res. Sup., August, 1940, pages 281s–292s, 4 illus., 10 tables.

What's New in Welding Equipment. Principal developments in welding apparatus have been in resistance welding machines, including spot, projection, butt and gun welders. An extremely high-production multiple spot welder has been built for the automotive industry. There is a trend toward a standardization of sizes of spot welders. Among the arc welders described are several transformer types as well as generator types. In gas equipment advances are confined to cutting machines and gas regulating devices. *Iron Age*, September 12, 1940, pages 52–56, 18 illus.

Meteorology

Transmission of Infra-red Radiation through Fog. P. N. Smith and H. V. Hayes. By use of proper equipment, it is possible to detect and measure the energy of infrared rays, 3μ and more in length, through the worst conditions of the atmosphere and ambient illuminations to distances considerably greater than the limits of "visibility." A large part of the energy received from such sources as were used in the tests described is composed of energy scattered by the fog. Device described was developed and used to receive and measure the energy reaching the receiving station under all atmospheric conditions and fulfills all requirements known to the authors. Of the radiation from a hot source the longer rays suffer less attenuation in passing through a fog than the shorter visible or nearly visible rays.

Tests to check results of the Hayes report were made over Boston Harbor and new and similar tests were made with the same apparatus virtually at sea and during times of the heaviest fogs found on the Massachusetts coast. Receiver was the Hayes radiometer. A water filter with glass faces for band I, a red sextant glass for band II, and a magnesium-oxide filter for band III were used. Results of these tests with different sources and with the three filters are shown diagrammatically directly beneath curves derived from results of field tests. *Optical Soc. Am., Jour.*, August, 1940, pages 332–337, 5 illus., 1 table.

Weather to Fly or Whether to Wait. Capt. F. Smith, Canadian Colonial Airways. Decisions affecting proposed flights to be made in the conventional private-owner type of aircraft (a single-engine pleasure ship with standard equipment) are described. A flight of about 275 miles is used as an example. *Aero Digest*, September, 1940, pages 51–52, 184, 3 illus., 1 map.

Production and Operation of Military Aircraft

AUSTRALIA

Progress in Australia. First Bristol Beaufort to be built in Australia will be delivered in April, and by the middle of 1941 production will be at the rate of one a day, the whole contract to be finished by the first half of 1942. Bristol Taurus engines will be replaced by Pratt and Whitney 1200-hp. Twin-row Wasp engines which are to be built in Australia, production to start early next year. Deliveries to Australia of the manufactured parts and materials for the first 20 Beauforts will be completed shortly. Australia's part in the Empire training scheme is to be speeded up during the next three of four months and is already ahead of the Ottawa program. Seven more stations for the scheme are to be opened during the next few weeks and will include the first bombing and gunnery school to be established under the scheme. Brief note. *Aeroplane*, August 16, 1940, page 165.

GERMANY

Warplane Factories in Germany. P. H. Wilkinson. Germany has a capacity of 50,000 warplanes a year right now without expanding existing facilities, according to what the author saw when he visited its factories last year. These factories are not working at maximum capacity but only produce replacements and reserve airplanes and engines for the vast air fleets. The tremendous production facilities of these factories could be thrown into high gear immediately with unlimited supplies of material and trained personnel at their command.

Entire German Air Force is built around three gasoline engines, the 1200-hp. Junkers Jumo 211, the 1200-hp. Mercedes-Benz D.B.601 and the 1000-hp. B.M.W.132. Thousands of Junkers Jumo Diesels of from 700 hp. to 1500 hp. have been produced for a special long-range bombing fleet. Aircraft engines in Germany are built along mass-production lines similar to those for airframes, and engine factories can supply the needs for 50,000 warplanes a year. Latest Heinkel bombers have a speed in excess of 300 m.p.h. with full load. Considerable quantities of He.112 single-seater fighters having a speed of approximately 375 m.p.h. are beginning to make their appearance armed with two shell guns and a number of machine guns. The twin-engined Me.110 two-seater fighter has a speed of 380 m.p.h. at high altitudes and sufficient flight range for convoying bombers. At Friedrichshafen sturdy Do.24 three-engined patrol flying boats having a speed of 200 m.p.h. and a flight range of 2200 miles were being turned out. Landplane production at Dornier was confined to Do.17 and Do.215 twin-engined bombers having a speed in excess of 300 m.p.h. and a ceiling of 30,000 ft., some powered with B.M.W.132 aircooled radials and others with Mercedes-Benz D.B.601 engines. Junkers warplanes in production consist of the Ju.87 dive-bomber (Stuka), the Ju.88 twin-engined high-speed bomber, the Ju.89 four-engined heavy bomber, and the Ju.53 three-engined transport plane. Numerous Ju.86-K twin-engined long-range bombers powered with Diesels have been produced for the Air Force. To be continued. *Aviation*, September, 1940, pages 44–45, 132, 4 illus.

Oil and War—Some Oil Figures as They Affect the Present Struggle. Gasoline used by German aircraft on a day of raiding the British Isles when a total of something like 400 enemy airplanes appear around the coasts is considered. Figures of 55 and 110 gal./hr. for the single-engine and twin-engine types, respectively, and a total of 100,000 gal. or 360 tons are arrived at. As a prelude to an invasion attempt, for an air attack of 4000 airplanes which would remain in the air 5 hr./day, consumption per day becomes 6000 tons.

"When it is remembered that all this is high-octane fuel (87 and 100), the daily consumption becomes impressive and undoubtedly could not be kept up for very long. But for how long? That is not known. It depends on the amount stored in Germany before the war, the rate of output of gasoline from coal, the stored gasoline obtained by the conquests of Denmark, Norway, Holland, Belgium, and France, and the subsequent destruction wrought by bombing." Tables give oil production and consumption figures for 13 important countries before the war, and an analysis of annual exports from the United States to Japan, the British Isles, and all other countries. *Flight*, August 15, 1940, pages 127–128, 2 tables.

The Fuel Situation. Probable effects of President Roosevelt's ban on the export of aviation fuel outside of the Western Hemisphere are considered from a British point of view. The critical position of Germany in regard to gasoline is pointed out, and German requirements, sources of supply, stocks at the beginning of the war, and synthetic production, as well as the Italian balance sheet of annual needs and home production, are discussed. The whole of the French plants working on the Bergius process would be able to turn out about 2 1/2 million tons for the Luftwaffe at present production rates.

"If Germany can obtain the whole Rumanian output she will have at least 10 million tons of fuel a year at her disposal. This is not sufficient to maintain a 'total' war on a large scale for any length of time, nor does it take into account the effect of the bombing of plants and stocks. But it is enough to maintain the war with a period of short offensive operations. Italy is a millstone in this aspect of the war. . . . . Thus Germany will have to supply Italy from her own insufficient stocks. All these factors account for the desperate steps Italy is taking in an effort towards gaining control of the oil-fields in Iraq for the use of the Axis powers." *Aeroplane*, August 16, 1940, page 168, 1 table.

U.S.A.

Niles-Bement-Pond Company's Pratt & Whitney Division. A. Kahn. Entirely new plant of the tool company located in West Hartford, is 1000 ft. long and 550 ft. wide. It comprises a main manufacturing building, an administration building and a separate unit composed of a pattern and storage building with an adjoining garage and boiler house. The one-story manufacturing building is 960 ft. × 520 ft. with 182 ft. × 40 ft. wings. Long description of layout and construction of plant. *Aero Digest*, September, 1940, pages 43–44, 47–48, 8 illus.

Plastics in U.S. Defense Economy. Strategically important, plastics have been found to be amply available and their increased production possible. Position in regard to phenol-formaldehyde, cellulose acetate, ethylcellulose, ureaformaldehyde, acrylic resins, vinyls, polystrene, casein, molders, laminators and fabricators, and the Springfield plan are discussed. *Modern Plastics*, August, 1940, pages 25–28, 96, 97, 3 illus.

Air Forces

GREAT BRITAIN

The Big Bombers. C. G. Grey. In Hampden bombers the single slow-speed popguns have been replaced by twin high-speed guns above and below, and traverse of the guns has been vastly improved by a new form of mounting which was developed in the first place by local ingenuity and private enterprise. Result is that the Hampden gunners can now do a lot more to tackle fighters coming in sideways. None of the standard bombers is the same as it was when the war started. Latest pride of the Hampden squadrons is the ruination of the Dortmund-Ems Canal. Comments on the work of the bomber squadrons. Continued. *Aeroplane*, August 16, 1940, pages 173–175, 3 illus.

SIAM

Aviation Makes Progress in Siam. L. Zacharoff. Aeronautical situation in Siam. Although there are no native aircraft manufacturers in Thailand and the Air Force depends on such importations as the Curtiss Hawk,

Vough Corsair, Martin Bomber and Avro 504N, there are military workshops building experimental planes. Local designers and constructors have been trying out indigenous timber in some of their experiments. Commercial aeronautics is also discussed. *Aviation*, September, 1940, pages 58, 128, 2 illus.

U.S.A.

In America—In Germany. C. C. Moseley. "The private aviation schools in this country are doing a superb job in preparing mechanics for the Air Corps." Account of the air defense program at the Curtiss-Wright Technical Institute. Photographs on another page show four lessons in the training of the Nazi youth for aviation. *Aviation*, September, 1940, pages 36–37, 128, 7 illus.

Air Warfare

Air Blockade. Capt. Norman Macmillan. First issue—Britain's air blockade must reach East Germany. "What we need are bombers with a much greater range, obtained without sacrifice of bomb load. They are needed urgently even as temporary types pending the delivery of others with still greater range and bomb load. Everything needed to permit them to operate should be put in hand, so that the present air operations can be extended to the targets which lie beyond our present areas of attack." It is suggested that military aircraft use special runways for take-off on long-range flights. The necessity for shutting off the axis powers from the Islamic world in the air blockade of Germany, and the need for the active cooperation of the Islamic world with Britain are pointed out.

Second issue—The four air zones which Germany has to defend are described, and the necessity for bombing Zones 3 and 4, the farthest in Germany, is pointed out. "The kind of fighter needed for long-range work has not yet made its appearance on either side of the battle front. But before this war is very much farther on its way, the need for long-range fighters of a new kind will have become apparent, and a terrific demand will arise for them. . . . At the same time it will be absolutely necessary for the R.A.F. to be equipped with long-range bombers capable of dealing handsomely with every target in the areas, which I have called Zones 3 and 4. And if these bombers are to operate during daylight (which will be necessary in attacks made on this zone during summer months of 1941) they will have to be escorted. . . . In the meantime, we have the autumn to get on with the production of new types of aircraft suitable for the changed conditions under which the R.A.F. Bomber Command has to operate. If things are handled properly we ought to be able to raid Zone 4 effectively next year." *Flight*, August 15 and 22, 1940, pages 125–127 and 150–152.

Engine Design and Research

Design of High Speed, Two-Stroke Engines. S. Treves. Calculation of the supercharger and the supercharging ratio. The phenomena are discussed which take place inside the cylinder during the scavenging period when, for each unit volume entering through the inlet ports, an equal volume is expelled through the exhaust ports. Charge thus expelled generally consists in part of burnt gases and in part of fresh charge which has become mixed with them.

It is shown that whereas it is possible with the two-stroke engine to obtain very high specific outputs and very high b.m.e.p.—considering that a given b.m.e.p. in a two-stroke engine corresponds to twice that value in the four-stroke engine—the same low fuel consumption is not obtainable with a two-stroke as is possible with the four-stroke. It is recommended that efforts of designing engineers be directed particularly toward improvement in stratification during the scavenging period, with the view to further diminishing the amount of mixture lost through the exhaust ports, and to the provision of greater turbulence with a view to decreasing the difference between practical and theoretical cycles. Continued. *Automotive Industries*, September 1, 1940, pages 203–206, 1 illus., 14 equations.

Engine Maintenance

Expanding Pistons by Blast. Koetherizer apparatus installed in Wellworthy Service Depots for restoring worn pistons to their original size by the Koetherizing process, is somewhat similar to a sand-blasting machine. Its purpose is to subject certain parts of the inside of the piston skirt to the peening effect of a controlled shot blast. Blasting expands the piston skirt to the correct dimension and produces the required shape and taper. Skirt dimensions can be increased by as much as 0.005 in. over the original size. Few details of apparatus. *Aeroplane*, August 16, 1940, page 186.

Engine Manufacture

Controlling Quality of Production. Junkers methods for the inspection of raw materials and finished parts of aircraft engines involve the wide use of optical apparatus. Devices are illustrated for the following: checking the gear pitch and root diameters, tooth thickness and form, and checking against a master gear; simultaneous checking of all important surfaces of an injection pump camshaft; and testing piston-ring diameters. Duties of the control department are discussed, including: constant supervision over all engine parts with regard to accuracy and quality demanded; supervision of final assembly in order that subassemblies are made to the necessary tolerances; control of plant and equipment used in production processes; judging the quality of each part, the group parts, and the finished parts; and deciding whether a part is to be used in the assembly or rejected. Translated from German. *Aircraft Production*, August, 1940, pages 266–267, 7 illus.

The Dagger in Production. Operations on connecting rods and pistons for the Napier Dagger VIII aircraft engines are described in detail, and methods employed by the Laystall Engineering Company in machining the crankshaft for the Dagger are reviewed. System of assembly by units is outlined. Unusual design of the Dagger engine involves special problems of assembly. Central oil pipe has been omitted from the connecting rods, making for easier production while efficiency of lubrication system is apparently unaffected. *Aircraft Production*, August, 1940, pages 246–252, 23 illus.

Notes on Methods of Balancing. K. R. Hopkirk. Conditions essential for accurate results in balancing shafts; selection of instruments for measurement of vibrations arising from unbalance, and principles of a simple device made from components easily obtainable; and conclusions arising from a consideration of the dynamic aspect of the problem involved in shaft marking. Concluded. *Engineer*, August 2, 1940, pages 72–73, 2 illus.

Engines

Junkers Jumo 211. P. H. Wilkinson. The 1200-hp. Junkers Jumo 211 aircraft engine, which is described in detail, is now being used by the German Air Force in its Stuka dive-bombers as well as in high-speed Junkers Ju.88 bombers, and in Heinkel bombers and fighters to an appreciable extent. High power output is obtained by means of a two-speed supercharger, low weight is made possible by refinement of design, compactness is obtained by building the engine with its cylinders in an inverted vee, economical fuel consumption is obtained by means of direct fuel injection, and reliability is insured by exercising the most rigid inspection control during the process of manufacture. Performance has been considerably improved and the engine now has a rating of 1200 hp. at 6500 ft., 1000 hp. at 16,400 ft., and 1200 hp. for takeoff, outputs all being obtained with 87-octane gasoline. Engine is a 12-cylinder water-cooled 60° inverted-vee gear-drive four-cycle type. Weight 1290 lb. or 1.07 lb./hp. Bore and stroke 5.90 × 6.50 in. Displacement 2136 cu.in. Length and area 69 in. × 6.9 sq.ft. Fuel consumption 0.45 lb./hp.-hr. Oil consumption 0.020 lb./hp.-hr. *Aviation*, September, 1940, pages 52–53, 132, 2 illus.

Some Details of the Rolls-Royce Merlin X Engine. Design is rather complicated and comprises a very large number of parts which must add to the time and cost of production and render maintenance more difficult, according to these German comments on the Merlin X engine which is to be produced in this country in large numbers. For instance, when it is desired to remove the cover plates from valve housings, a very large number of capscrews must be taken out. While design indicates that little attention has been paid to production and maintenance, all details are worked out with great care. Owing to the arrangement of the blower on the engine and to the location of such parts as inlet manifolds, ignition harness, and charge and cooling-water equalization pipes in the vee, it is impossible to mount a cannon concentric with the propeller shaft and shooting through the latter. Although with the design chosen it was difficult to obviate the use of bolts through the diffuser, injurious effects of these bolts on airflow are prevented by letting them form part of the diffuser vanes and giving them a flat cross section. Merlin X 12-cylinder liquid-cooled engine has a two-speed blower and develops nearly 1100 hp. at 3000 r.p.m. for take-off. *Automotive Industries*, September 1, 1940, page 206.

PARTS AND ACCESSORIES

A New Coupling for Shafts and Pipes. Coupling recently patented in Germany has been designed to avoid the use of keys, spline shafts or press fits for joining cylindrical shafts. End of shaft fits inside the extension of the coupling which supports a clamping ring. Both the inside of the clamping ring and the outside of the coupling extension are tapered to the same angle which may be between 1 in 30 or 1 in 50. Cylindrical rollers located between these surfaces are guided by a cage in such a way that roller axis is inclined to the shaft axis at an angle. With a relatively small force a very high pressure can be generated between the rollers and the conical faces. Forces or torques to be transmitted are carried only through the shaft and extension of the coupling and exert no stresses on the rollers. Loosening of the coupling by shocks or vibration is not possible and the roll coupling is said to have a centering precision not obtained with other kinds of detachable connections. Short description and drawing. *Aircraft Production*, August, 1940, page 255, 1 illus.

Aircraft Radio

Aero Radio Digest. Bendix automatic aircraft radio direction finders, including: Model MN-31 consisting of an improved MN-26 receiver and MN-28E remote-control unit; Model MN-36A station-seeking loop with its MN-31A loop control unit; MN-37A 360° azimuth indicator; and necessary cables and junction box. Two new RCA aeronautical ground-station communications transmitters, the 2500-watt Model AVT-22 and the 5000-watt Model AVT-22A. Finch Telecommunications mobile field laboratory unit, housed in a specially built automobile trailer for two-way tests of their equipment in conjunction with their aircraft. Leach r-f relay designed especially for low power aircraft transmitters. Dry-cell-powered Waller Transceiver Model B intended primarily for private pilots and announced by the Spartan School of Aeronautics. *Aero Digest*, September, 1940, pages 175–176, 11 illus.

Aviation Radio. D. Fink. Taylor standard Model BR-4 receiver and BT-4 transmitter mountable in a luggage-type carrying case resembling that of the usual portable radio receiver. Radio Receptor Model 421 U-h-f transmitter for airport traffic control and the Series 42 U-h-f receivers intended for airport traffic control and for general communications purposes being available in 60 to 66 Mc, 123 to 128.5 Mc, and 140 to 144 Mc. The most powerful airline ground-station transmitters yet used in this country having a power output of 5 kw. and being installed for United Airlines by the Federal Telegraph Company. *Aviation*, September, 1940, page 64, 2 illus.

Tubes at Work. "A Flexible Beam Power Transmitter," E. F. Kiernan, Western Air Express Corporation "A Multifrequency Tuned Antenna System," H. K. Morgan, T.W.A. "Measuring Characteristic Impedance of Twisted Pairs," A. Alford. "An Electronic Telescope Control," A. L. Rubenstein. "A Fluorescent Lamp Voltage Stabilizer," described by M. H. Sweet. Long descriptions. *Electronics*, August, 1940, pages 40–58 (alternate pages), 19 illus., many equations.

Radio Design and Research

Remote Control of a Model Boat. W. P. West. By means of the radio remote-control system described the 5 ft. model ship "North Star" may be made to maneuver in a manner very much like its prototype both as to operations performed and relative speed of response. Boat is driven by a battery-powered 6-volt motor and steered by means of a motor-driven rudder. Operations of both are controlled remotely by a radio system making use of a telephone dial to transmit a number of impulses for any desired operation and a stepping switch in the receiver which causes the correct relay to set in motion the maneuver called for by the operator on the shore. *Electronics*, August, 1940, pages 19–21, 5 illus.